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# Man and Environment

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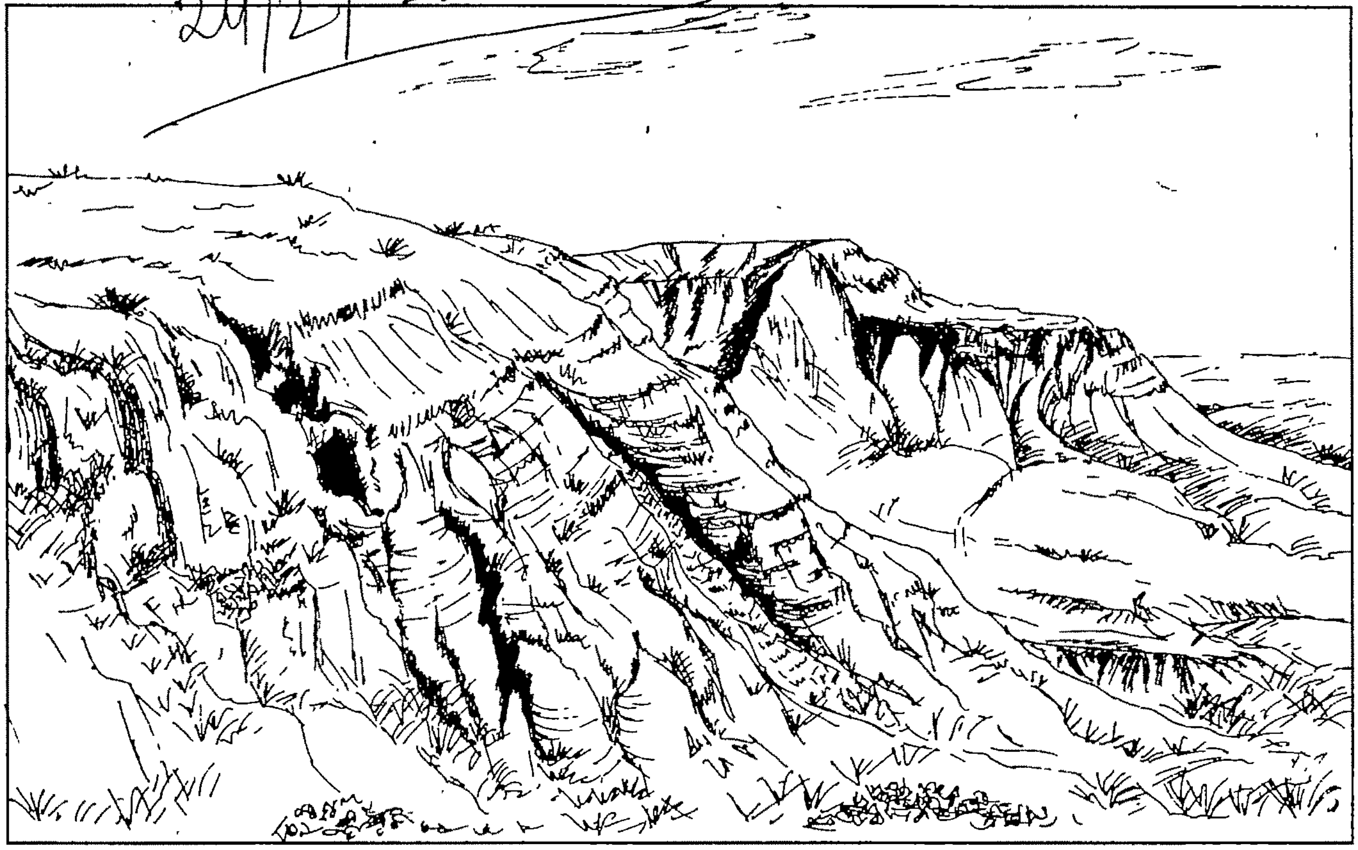

Indian Society for Prehistoric and Quaternary Studies

# Man and Environment

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*Cover*: Early Holocene Tuffa near Modalwadi overlooking Chandanapuri Ghat. Sketch by Dr. Savita Ghate.

# Editorial

The present volume is a special volume comprising the proceedings of the first workshop for IGCP-413 (Palaeomonsoons and Desert Margins) and the third workshop for IGCP 349 (Understanding Future Dryland Environmental Changes from Past Dynamics) which was held at the Department of Archaeology, Deccan College, Pune, December 8-11, 1998. Thirty-two papers were presented at the workshop out of which sixteen authors have submitted their papers to the special volume which comes out less than a year after the workshop In spite of the short time between the workshop and submission of manuscripts, all the papers have been reviewed, revised and edited as for a normal issue of our Journal.

The issue is divided into three sections: Deserts and Desert Margins, Monsoons and Floods, and Geoarchaeology and Palaeoenvironmental Records. The first section has nine papers. A great diversity of topics and regions are represented. While Achyuthan provides data on some of the ferricretes from the Thar desert, Deotare *et al.* document a 1500 yr old ephemeral feeder to the Bap Malhar Rann, providing some data on the post playa history of the desert. Thomas discusses some of the issues in interpreting aeolian records and Derbyshire presents interesting information about loess records from Argentina. Dating results of aeolian sediments are presented by Chougaonkar *et al.* and Zhong-Ping *et al.*, Mishra *et al.* study a Luni palaeochannel fragment from a multidisciplinary perspective. Wadhawan provides a detailed lithostratigraphy for a sub-basin of the Thar desert along with a palaeoclimatic interpretation of the various units. Raghav and Sinha present their detailed study of modern dunes and an interpretation of the factors influencing them. In the sections on palaeomonsoons and palaeofloods Sontakke and Singh analyse the 200 year instrumental rainfall record for India to make a prediction for the rainfall in the next decade. On the other hand, Gupta uses microfossils from an ocean core to analyse the response of climate to the earth's orbital forcing over the last half a million years. Kale provides a summary of the results of his studies of palaeofloods over the last decade.

Geoarchaeological and palaeoenvironmental studies are reported in two papers by Misra *et al.* from the Narmada and Vel rivers. Paddayya *et al.* give some interesting information about the Acheulian site of Isampur, and Lehmkuhl *et al.* make an exhaustive review of the Late Quaternary palaeoclimate of the Tibet plateau along with a reconstruction of the environmental parameters of the Neolithic period when the plateau had an increased population.

We hope this timely publication will help scholars in this field and also disseminate the findings to a wider audience.

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# The International Geological Correlation Programme: Geoscience in the Service of Society

Edward Derbyshire

Chairman
IGCP Scientific Board

The International Geological Correlation Programme (IGCP) was created in 1972 by UNESCO in order to facilitate worldwide collaboration between geoscientists working on vital problems concerning the earth and its resources. The Programme was specifically designed to promote the exchange of ideas, data and techniques, to encourage and assist the training of geoscientists, and to enhance quality control of the world's geoscientific information. IGCP projects are open to scientists from all nations, and may be led by scientists of any nationality.

The 27 years since the establishment of the IGCP has been a period of momentous change - political, economic and social. The IGCP began in the atmosphere of the "cold war". In the best spirit of UNESCO it provided a means to ensure that earth science crossed international boundaries. The quality of the science produced by IGCP Projects was impressive, and this led to the crossing of many international boundaries. Indeed, it provided a kind of "passport" to many earth scientists especially from Eastern Europe. IGCP has continued to reach out to the nations, and increasingly to those in the developing world, as socio-political conditions have continued to change. It has progressively adapted its operations, although without losing sight of its overall philosophy emphasising trans-national collaboration on key issues relating to geology, environment and humankind.

Thus, despite changing times, and changing priorities within IGCP as UNESCO moves increasingly towards emphasising multidisciplinary initiatives and global approaches to major environmental problems, IGCP retains its attraction for earth scientists. This certainly cannot be explained in terms of funding, because all IGCP is able to offer is base-line support or "seed money" to help scientists communicate and meet each other from time to time In recent years, the highest level of annual support (for which a Project is required to obtain an "Excellent" rating at the annual review) has been between $9,000 and $10,000, the average level of support having been $5,000 per project). The real basis of the continuing attraction exercised by IGCP derives from its truly global and wholly scientific perspective these projects provide. A practical verification of this is to be seen in the way many individual IGCP Projects attract considerable additional funding from sources other than UNESCO and IUGS. It is demonstrably true that, year after year, the according of IGCP status to a Project is seen as a mark of quality by national and international funding agencies. It thus appears that the "grass roots" basis of the IGCP and its truly international "workshop" ethos is also close to the heart of its continuing attraction.

Project proposals generated by international teams of geoscientsists can be submitted for approval at any time, but the annual deadline for such proposals is the end of September. All Project proposals received at the IGCP Secretariat are rigorously assessed at the annual meeting of the 16-strong Scientific Board at UNESCO Headquarters in Paris in late January-early February. Award of Project Status by the IGCP Scientific Board depends upon the suitability of the Projects within the framework by the theme "Geoscience in the Service of Society". In addition to scientific excellence, promise and timeliness, the Board emphasises a number of other criteria in evaluating new proposals. These include the extent to which the proposed Project's objectives match those of the IGCP, the number and distribution of nations to be involved in the Project (usually a minimum number of 20), the level of involvement of the developing countries, the "training" and "capacity building" elements in the programme, and its societal relevance. Once approved, IGCP projects are subject to annual critical review by the Board during the normal time-span of five years.

The IGCP is managed jointly by UNESCO and the International Union of Geological Sciences (IUGS). Several thousand scientists from more than 150 countries have participated in the Programme over the past 27 years. Like all dynamic scientific undertakings, it evolves continually in response to new discoveries and concepts and to the changing emphases and demands arising from social needs. The scientists, whose freely-given efforts have made the IGCP the most successful international programme of its kind, have made fundamental contributions to understanding earth systems and relating these findings to real-life problems ranging from the search for, and utilisation of, natural resources to the investigation of global warming. For example, the modest "seed money" provided by UNESCO and IGCP led to the development of a global model of essential commodities such as phosphates. Similar successes can be claimed for work on the presence of toxic chemicals in the vital natural resources of soil and water. Soil and rock chemistry also has a bearing on human health, as shown by an increasing number of geochemical-epidemiological studies around the world. A number of IGCP projects have also shown that the more recent sediments on the Earth's surface contain a detailed record of climatic change against which can be set the evidence of human-induced changes over the past century. These and many other IGCP investigations have involved several thousand geologists from the developing world, and many have included advanced training components in line with the scientific, educational and cultural aims of UNESCO.

The results obtained by a number of IGCP projects leave no doubt that geoscience has a vital role to play in providing a temporal framework for change. Planners and decision-makers concerned to make provision for a major natural event with a return period of say, 50 years, require a record going back at least 500 years. Similarly, concern with a particular 500-year event, demands a record extending back at least 5,000 years. A fundamental element in any regional planning strategy must be the latest and best available evidence of past environmental changes, for the past is the only reliable key we have to sound future planning. The nature and global view of many IGCP Projects give them an obvious value within such a philosophy.

# International Geological Correlation Programme (IGCP-413) on Understanding Future Dryland Environmental Changes from Past Dynamics

D.S.G. Thomas and A.K. Singhvi[1]

Department of Geography
Sheffield University
Sheffield, S10 2TN, UK

1 Earth Science Division
Physical Research Laboratory
Ahmedabad 380 009, India

## Abstract

IGCP-413 focuses on creating, collating and synthesizing global data from the world's deserts and drylands. Recent developments in dating techniques and quantitative palaeoclimatology have led to significant advances in the understanding of the timing and amplitude of environmental changes in deserts and desert margins. It is now possible to address questions such as whether changes in different deserts occurred synchronously and whether hydrological changes in the deserts coincided with enhanced aeolian activities. These advances can provide a valuable data set for the validation of regional and global general circulation climate models and can also provide valuable inputs for land use planning strategies.

## Introduction

Deserts and drylands cover nearly 50% of the global land area (UNEP 1992). These environments present many challenges for their human populations in terms of land use planning, water resources and agriculture. In these areas, human populations are set to face increased problems in response to growing population pressure with increasing demand on water resources and the possible impacts of anthropogenically caused climatic changes (e.g. Heathcote 1983; Thomas and Middleton, 1994; Williams and Balling 1995; Warren *et al.* 1996). The drylands of Africa, the southern States of the former Soviet Union, the Thar Desert of India and the American southwest are typical examples. It is now widely accepted that an understanding of past climatic and environmental variability will be a crucial component of climate modelling studies that could be eventually used for future predictions (IGBP 1994). It is equally important to establish the response of diverse geomorphic processes to climatic fluctuations. The significance of these studies to society cannot be overemphasised as almost 20% of the global population resides in drylands. In Africa alone 50% of the population resides in drylands.

Deserts and their margins have not been studied in sufficient detail. Qualitative studies on the deserts indicate that large amplitude changes in geomorphic processes occurred during the past. Dating these changes however, had been difficult earlier. One of the major methodological advances is the recent developement of dating techniques such as luminescence dating, accelerator mass spectrometric (AMS) radiocarbon dating and thermal ionization mass spectrometry which have a wide applicability to desert environments (Singhvi *et al.* 1982; Dickin 1995). Aspects such as the role of extreme events, the importance of understanding climatic and geomorphic thresholds in drylands can now be quantified by a variety of techniques (e.g. Thomas 1997; Singhvi and Derbyshire 1999). The present projects thus aim to:

1. identify regional and hemispheric differences in the timing of Late Quaternary desert margin fluctuations by dating and collating records of aeolian dynamics. This will help to address the question of whether the world's deserts expanded and contracted synchronously, which was first discussed by Sarnthein (1982). This has implications for the timing of desert albedo changes,
2. collate and synthesise data on the magnitude of hydrological changes in drylands, their response times, the role of extreme hydrologic events in landscape evolution and their chronology using lacustrine and cave speleothem records, etc.,
3. understand past human occupations and their relationship with environmental changes by reference to geoarchaeological studies,
4. improve the understanding of the role of the terrestrial carbon system..This will help in understanding of the timing and hydrological relationships of Late Quaternary pedogenic carbonate formations and to assess their impact on the global carbon budget,

5. elucidate role of high magnitude and rapid sedimentation /erosion events in dryland landscape development. This is important for understanding the stability of dryland systems and their possible impact on populations under future climatic changes;
6. the collation and synthesis of related data on aeolian dust/loess from drylands;
7. attempt to produce maps and databases from the above so that they could be used in the validation of general circulation climate models and in long term planing of desert and peri-desert regions.

### Scientific Context of IGCP- 413 Objectives

#### *A) Changing deserts: past to future*

Research from a range of disciplines over the past decade indicates that margins of deserts have fluctuated significantly during the Pleistocene and Holocene (e.g. Alsharan *et al.* 1996; Petit-Maire 1994). Scenarios for the future impact of greenhouse induced global warming indicate that many of the drylands will experience enhanced mean temperatures and aridity (e.g. Williams and Balling 1995). Consequently a change in the operational domains of geomorphic processes and their intensity is to be expected. For example, expansion of deserts would have implications for the agricultural output in the marginal regions (Parry 1990). The exact timing and rates of such processes need to be established.

#### *b) Spatial variability in drylands*

Drylands display large internal variability. This arises because of basic differences between hyper-arid to arid, semi-arid and dry sub-humid environments (Cooke *et al.* 1993) These categories based on climatic criteria (UNEP 1992) offer different potentials for human activities and represent significant differences in the operation of hydrological and geomorphological processes. Process accelerations that take place in climate transitions are likely to affect the marginal regions more than the regions of extreme climates. The improved understanding of Quaternary desert fluctuations is in many ways represented in terms of general hydrological changes rather than with reference to specific changes within the dryland domain. The present project will aim to generate a better understanding of the resolution and process domains by improving the quality of data on palaeo-surfaces (e g. vegetation and exposed surfaces at key time intervals. The results will provide a better appreciation of the timing and amplitude and regional variability of albedo changes.

#### *c) Anthropogenic component: past and present*

Societies in deserts are both "impacted upon" and "impact on" climate induced changes in drylands. Future variability and climatic change in many areas will result in enhanced desertification (Williams and Balling 1995). Overall it is considered that traditional societies are better adapted to environment in drylands compared to modern ones (e.g. Mace 1991), though evidence of ancient societies contributing to desert expansion does exist (Mainguet 1991). In general human activity signifies an improved hydrological regime, but a greater understanding of past desertification episodes, their relationship to climate and population pressures (O'Hara *et al.* 1993) is needed.

#### *d) Temporal variability: amplitude and forcing mechanism*

Despite recent technological advances many key issues relating to the fluctuations within deserts and their margins remain unresolved and poorly understood. These relate to the timing, nature and forcing mechanisms of Late Quaternary desert fluctuations (e.g. de Menocal *et al.* 1993) particularly in respect of inter-hemispheric comparisons and contrasts and their explanations (e.g. Shaw and Thomas 1996). Recent studies indicate that despite a general overall coherence, different deserts may have had different response times to climatic perturbations This implies the need to first tackle different regions as independent entities and then attempt a comparison between deserts based on securely dated climatic records. Indeed, increasing evidence indicates that some of the difficulties in climate modelling may be due to poor resolution of data inputs arising from simplified interpretations of past desert changes, their assumed timing and assumed global teleconnections.

#### *e) Drylands and global carbon budget*

It has long been considered that deserts can be global sources and sinks of carbon (Schlesinger 1985; Adams *et al.* 1990) Research on shifts in desert margins, associated changes in vegetation, formation of pedogenic carbonates at specific stratigraphic levels all point to the potential of drylands in carbon sequestering. Pedogenic carbonates have been considered important both as a stratigraphic and palaeoprecipitation indicators (Rettalack 1992). Recent developments in estimating the timing of formation of these carbonates (Singhvi *et al.* 1996) provide potential to improve the understanding of the role of drylands and their margins in the carbon cycle.

### Organisation: Core Research Groups

To achieve the above objectives three core groups each with a well defined theme but with an overall perspective have been created. These are:

a) *Aeolian styles*: This will address enhanced chronologies of Late Quaternary aeolian activity, hemispheric contrast in the magnitude and timing of palaeo-aridity, causal relationships between aridity and aeolian dynamism and aeolian activity in high magnitude events (droughts), styles of aeolian activity and resultant sediments, Holocene, historical and modern records of human occupation in relation to climate change and desertification.

b) *Hydrological dynamics*: This component will address the timing and amplitude of hydrological changes in drylands, the role of extreme events, the role of palaeofloods, changes in ecology and pedogenic processes, controls on and the timing of dryland pedogenic records, records from cave deposits and human contribution to hydrological risks.

c) *Human dynamics and geoarchaeology*: This will aim to collate the geoarchaeological record of drylands and deduce human impacts on desert process especially during the Late Holocene and historical periods, historical records of man induced desertification and human response to dryland changes.

## Implementation: Present Status

IGCP–413 formally began in 1998 and so far three major thematic meetings (Oxford, Pune, Durban) have been held. The next meeting will be held in Zyzaxx during October 22-30, 2000, near Las Vegas, USA and will be organized by the Desert Research Centre, Reno, Nevada, USA Scientists from 29 countries have been actively participating. Several special issues of international journals — one issue each of the *Journal of Arid Environments*, *Earth Surface Processes and Landforms*, *Zeitschrift für Geomorphologie*, *Man and Environment* and *Quaternary Science Reviews* and an edited book *Aeolian Environments, Sediments and Landforms* are in the process of publication. A detailed report on the activities of the present IGCP is available from the authors and will be published in the IGCP Newsletter 1998. Its website (http://www.shef.ac.uk/~igcp413/) also provides all the details.

## Acknowledgements

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# The Pune IGCP–349/413 Workshop

Sheila Mishra and Savita Ghate[1]

Department of Archaeology
Deccan College
Pune 411 006

The first workshop for IGCP 413 (Palaeomonsoons and Desert Margins) and the third workshop for IGCP 349 (Understanding Future Dryland Environmental Changes from Past Dynamics) was held at Deccan College, Pune between December 8 and 11 1998. Two earlier workshops for IGCP 349 had been organized at Jaipur by the GSI in April 1995 and at M.S. University of Baroda, Vadodara in November 1995. As Deccan College has been working in the Thar desert for a long time, a group from Deccan College attended both these earlier workshops. However it was not only the work in the Rajasthan which has a relevance to the IGCP themes, but also the palaeoclimatic record from western Maharashtra. At both the previous workshops the similarities between the climatic records of western Maharashtra and the Thar and its margins were reported. Both the previous workshops had been great successes and the field trips and presentations had provided a forum for critical discussion. It was for these reasons that Deccan College, Department of Archaeology was invited to hold the workshop.

Many people cooperated to make the workshop at Pune a success. Dr. V.N. Misra, Director, Deccan College, Dr. K. Paddayya, Head, and Jt. Director, Department of Archaeology, Deccan College, Dr. G.B. Pant, Director, Indian Institute of Tropical Meteorology, Dr. S.D. Powar, Director, Pune Office of the GSI and Dr. Arun Nigevekar, Vice Chancellor, Pune University formed the Advisory Committee. All these people and the institutions they represent helped in planning and provided institutional support. The working committee consisted of Sheila Mishra, B.C. Deotare, Sushama Deo, Savita Ghate, S.N. Rajaguru and M.D. Kajale. Close cooperation of this group made the preparations and planning of the workshop run smoothly. Drs. A.K. Singhvi and D.S.G. Thomas, the co-leaders of both the IGCP programmes also provided financial and moral support.

The workshop was inaugurated by Dr. S.K. Acharyya the Director General, GSI. Dr. Edward Derbyshire, Head, UNESCO, IGCP addressed the inaugural function and presented a paper at the workshop. Dr. G.B. Pant delivered a special lecture. A number of people attended the workshop from outside India: Australia (Dr. John Magee), Germany (Dr. Lehmkuhl) and the UK (Dr. D.S.G. Thomas and Dr. P. Shaw) and China (Lia Zhongping). There were over 40 Indian participants, from Pune, Jaipur, Jodhpur, Delhi, Ahmedabad, Vadodara, Nagpur, Chennai, Dehradun and Goa. Papers were presented in sessions on Aeolian, Lake, Fluvial, Geoarchaeological and General sessions. It was a packed programme with a high quality of work presented.

A two day field trip was organized to show the participants the Quaternary record in western Maharashtra. Recently Mishra *et al.* (1998) have completed a DST sponsored project on the "Fluvial Response to Climatic Change in the Upper Godavari Basin." Many new ideas about the record had been generated during work on this project. In addition to the Deccan College group, Dr. Vivek Kale, Dr. Vishwas Kale of Pune University's Geology and Geography departments, and the Geological Survey of India have been working in the area. All these people were involved in the field trip. The field trip was planned to show the four major post-Deccan Trap "formations" in western Maharashtra — the High Level Gravels, the Chandanapuri Formation, the Bori Formation and the Upper Bhima Formation (Rajaguru *et al.* 1993). Chandoli, on the Ghod River gives a good exposure of the alluvium deposited during the phase of arid climate near the peak of the last glaciation. A $^{14}$C date of 19,380 B.P. was obtained from this gravel. This coincides with the original concept of the Upper Bhima Formation given by Kajale *et al.* (1976). Our recent work at the site, however has shown that this aggradational episode came to an end at 13,500 B.P. as shown by the dating of shells in a gravel which unconformably overlies this silt. The aggradational phases were separated by a period of soil formation seen in the well developed vertisol on the 19 kyr alluvium. This site was occupied by early farmers around 3.5 kyr (Deo and Ansari 1965).

At Bori, the next stop, the delegates were disappointed not to be able to view the controversial volcanic ash (Korisettar *et al.* 1989; Acharyya and Basu 1993, 1994; Mishra and Rajaguru 1996; Westgate *et al.* 1998) which has been submerged by the construction of a local weir. However we showed them the black clays which are characteristic of the Bori Formation and have similarities to the earliest horizons in many of the river valleys (Tiwari 1999). Most of the Acheulian sites, such as Gangapur (Sankalia 1952), Yesar/Badne (Sali 1967) and Morgaon (Kale *et al.* 1993) are associated with similar black fissured clays. In the Ghod River also such units underlie the Upper Bhima Formation. The Bori Formation in which the volcanic ash occurs therefore is similar to units which are associated in many cases with Acheulian artefacts.

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[1] Ambedkar College for Arts and Commerce
Yerawada
Pune 411 006

The third stop was at Gamanwadi, on the Chandanapuri Nala to view the anomalously thick sediment fills in the source regions of the Bhima and Krishna drainage. En route we could see the bedrock gorge near Bote which was filled with similar sediments and the Mula/Chas Valley filled from side to side. Although these units have been considered to belong to phases of Late Pleistocene aridity, Mishra *et al.* (1998) have suggested that they do not fit with the present day drainage pattern and may be older. Vivek Kale showed some features of tectonic disturbance in the units and Veena Joshi and Vishwas Kale (Joshi and Kale 1997) were able to discuss their work on the same units with the delegates.

On the second day the participants were shown the high level gravel at Nevasa and also the Acheulian gravel at Laxmi Nala. Palaeomagnetic reversals have been found in a black clay overlying the gravel at Laxmi Nala. The difference in the weathering of the underlying gravel was shown at the two localities. The mound at Nevasa has a record of human occupation from around 3 kyr onward (Sankalia *et al.* 1960). Gaps in the occupation between the Chalcolithic and Early Historical period and the Early Historic period and the Late Medieval period were identified. Scholars have speculated on the role of environmental change in these "gaps". The "soil" between the Chalcolithic and Early Historic period occupation could be seen in a section to the south of the mound. Our recent work has shown that the alluvium below the mound also has a number of hearths and other signs of human activity. It has been assigned to the Early Holocene as it pre-dates the Chalcolithic and post-dates the Upper Palaeolithic. The shifting of the Pravara channel after the period of Sant Dyaneswar (13th century A.D.), recorded in local tradition is also documented in the geological features at the site.

The field trip therefore gave the participants an opportunity to see some of the features of the Western Maharashtra Quaternary palaeoclimatic changes and for us to discuss some of our new findings with a knowledgeable and critical audience.

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# Climate and Environmental Change in Low Latitudes: Issues, Challenges and Examples from Quaternary Aeolian Systems

David S.G. Thomas

Sheffield Centre for International Dryland Research
Department of Geography
University of Sheffield
Sheffield S10 2TN
UK

## Abstract

After outlining reasons for the potentially poor preservation of palaeoenvironmental proxy data in arid areas, the utility of aeolian deposits and landforms in aiding Quaternary palaeoenvironmental reconstructions is considered. Principal data sources are sand seas, which are spatially extensive, and interactive systems, which are more localised. The former have been and continue to be widely used in environmental reconstructions, while the latter have great potential to contribute to robust interpretations. In all cases, the greatest utility is gained when a) palaeoenvironmental interpretations take account of the findings of modern process studies, which allow more realistic interpretation of the controls influencing aeolian processes, and b) chronometric applications are made directly to the deposits being investigated. Issues and problems are exemplified through consideration of recent research in the Kalahari of southern Africa.

## Introduction

This paper outlines and explores the significance of the palaeoenvironmental information that may be gained from the investigation of continental aeolian deposits of Quaternary age. The rationale for producing this paper stems from the recent methodological advances that enable complex palaeoenvironmental information to be gained from deposits that, until relatively recently, were difficult to chronometrically control and for which modern process analogues were deficient. There is strong theoretical and empirical evidence indicating that enhanced global aridity has been a characteristic of times of glacial maxima, in which respect Michael Sarnthein's landmark paper (Sarnthein 1978) hypothesised that approximately 50 percent of the global land mass between 30°N and 30°S was covered by active sand seas at the time of the last glacial maximum (Fig. 1). Sarnthein's calculations were based on the relatively limited terrestrial data available at the time, and on the identification of terrestrially-derived aeolian dust and sand components preserved in ocean sediment cores dated to this period.

Since 1978 major advances have been achieved in Quaternary chronometry and in aeolian process studies. Developments in the luminescence family of dating techniques (Aitken 1998) which may be directly applied to quartz deposits of aeolian origin (e.g. Singhvi *et al.* 1982), have provided directly dated chronologies of aeolian activity in many low latitude areas. As a result, aeolian deposits assumed to have been an artefact of last glacial maximum aridity are revealing a history of accumulation that is both spatially (e.g. Stokes *et al.* 1997b) and temporally (e.g. Nanson *et al.* 1992) more complex. At the same time, detailed empirical investigations of the links between wind energy and aeolian sand flux, and in the understanding of sand dune development (summarised e.g. in Lancaster 1995) have permitted an improved understanding of the environmental and climatic controls on the operation of aeolian processes. Together, these factors permit a much enhanced utility of aeolian sediments and relict aeolian landforms in low latitude palaeoenvironmental research, where previously relict aeolian forms and sediments had been assumed to be a simple function of enhanced aridity, itself forced by high-latitude ice mass growth.

Low latitude aeolian deposits are themselves now generating high resolution Quaternary palaeoenvironmental records in their own right, which are in turn being directly dated rather than placed in gaps within radiocarbon- and uranium-thorium- dated humid chronologies. Our understanding of palaeoaridity and palaeoaeolian events is therefore much improved. At a time when GCM assessments of 21st century anthropogenically induced climate changes predict an expansion of climatic aridity, reduction in soil moisture contents and increased frequency of drought events in many subtropical locations (e.g. Williams and Balling 1996), this improved understanding has significant relevance to society, as well as informing our understanding of the dynamics of environ-

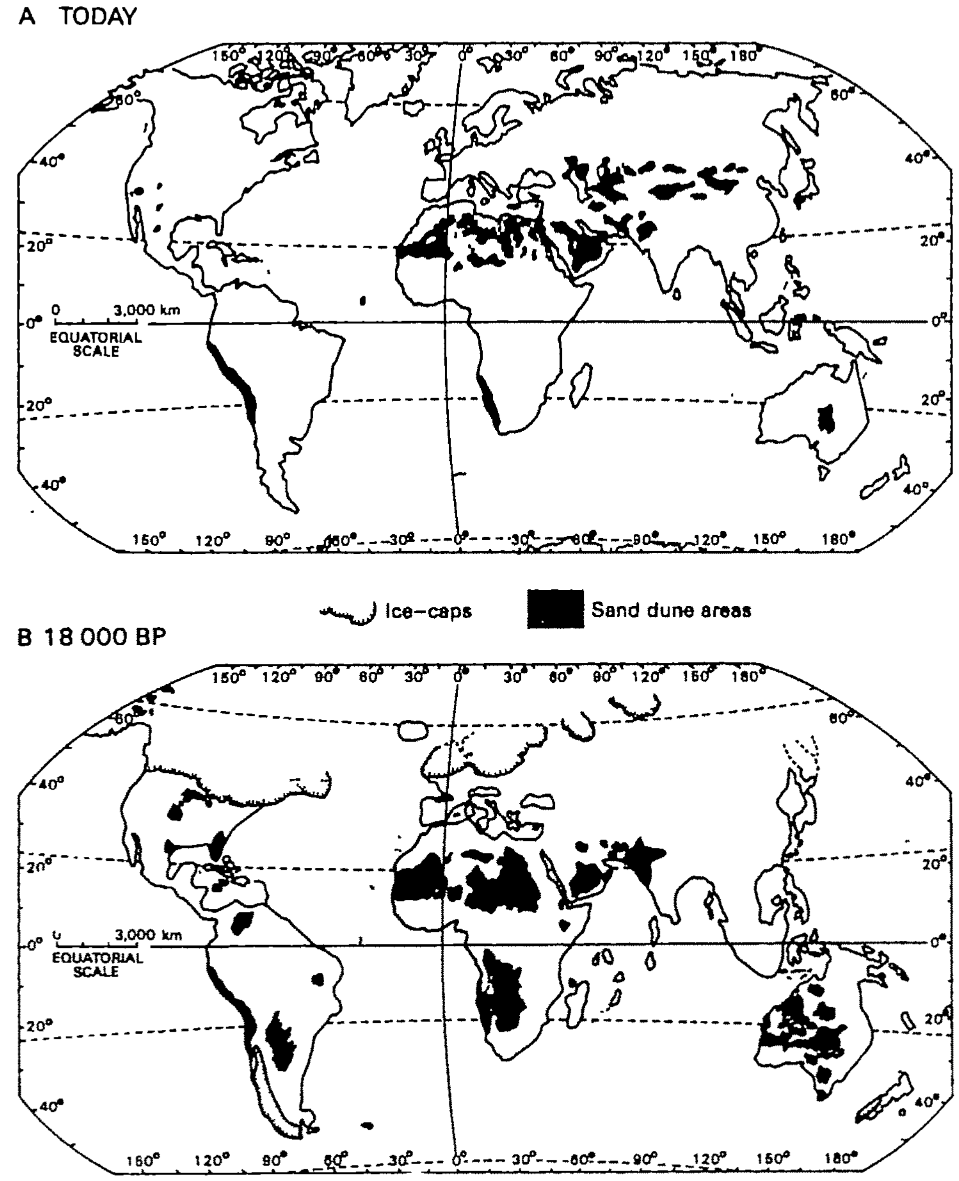

**Fig. 1:** The extent of active sand seas a) today and b) at the last glacial maximum (after Sarnthien 1978)

ments that were important for human evolution in the Pleistocene.

The focus of this paper is therefore the issue of gaining rigorous, reliable and environmentally meaningful information about Quaternary environmental change from low latitude aeolian systems. The central thesis has two parts:

- that the palaeoenvironmental signals from such environments are more complex than once believed, or that, due to problems of establishing chronologies of change, they have been fitted into frameworks derived from other environments and deposits;
- that the application of new techniques and the findings from aeolian process studies as analogues are leading to new challenges and findings of palaeoenvironmental complexity in Pleistocene aeolian systems, particularly but not exclusively in the low latitudes.

After initial consideration of the reasons why formerly-arid environments may yield poor palaeoenvironmental records, the focus will fall principally on gaining evidence from aeolian systems, exemplified through investigations in the Kalahari region of southern Africa.

## Problems of Establishing a Palaeoenvironmental Record

Several aspects of arid environments create significant difficulties for palaeoenvironmental reconstructions when compared with other key global environments and sources of data. Building on Stokes (1997), the following major issues can be discerned:

1. *Sediment accumulation is commonly episodic, short term, or at a slow rate*, with relatively short periods of activity punctuated by long periods of inactivity, in systems such as sand dunes and alluvial fans. In environments with changing arid-humid conditions evidence of the latter, e.g. from lake basins, may be much better represented.
2. *Closed sites, ideal for sequence preservation, may be spatially limited in occurrence*, further restricting the availability of accumulations that reveal long palaeoclimatic/environmental signals. This is, for example, particularly notable in the core areas of the Kalahari Desert of southern Africa (Thomas and Shaw 1991: Fig. 2).
3. *Arid environments are typically biomass deficient, in terms of production and preservation.* Biological indicators of environmental change may have very limited applicability in arid situations, due to absence of suitable materials. Even where palynological records exist, modern analogues for their robust interpretation may not exist.
4. In the driest areas, *soils are typically thin and poorly developed.* Palaeosols therefore have lower utility as indicators of change and still stands than in other situations.
5. *Surface and subsurface precipitates and duricrusts are potentially valuable datable materials.* These are generated by weathering, vadose diagenesis and lateral and vertical translocation of minerals. Problems of ground water contamination, formation after host sediment deposition, and episodic development, all hinder their utility in contributing reliably to chronology development. Thus in the middle Kalahari there are distinct separate peaks in the clustering of $^{14}$C dates derived from calcretes, which were widely dated in 1970-80 studies of palaeoenvironments (see Heine 1982; Shaw and Cooke 1986), and those from other sources, particularly shells derived from within calcrete matrices (Shaw and Thomas 1996). This distinction is likely to be because of progressive or multiphase phase calcrete development and/or contamination with younger carbon or percolating groundwaters (Chen and Polach 1986), rather than being indicative of real, distinctive, environmental changes.
6. *Many arid landscape components may have been exposed at the surface for long periods of time.* Landscape paralysis may mean that features have been inherited, with little alteration, from past regimes of great antiquity. Erosional paralysis, in parts of the Atacama Desert (Oberlander 1984) and in southern Egypt (Roper 1993) is a significant factor that effects the record of possible environmental changes in the Quaternary.
7. *The problem of lack of appropriate dating methods for key, aeolian, palaeoenvironmental indicators.* Until the 1990s in particular, geomorphic and sedimentological evidence of enhanced aeolian activity, resulting in aeolian sediment accumulation, could not be directly dated. By necessity, this evidence was therefore set within gaps in regional humid chronologies (e.g. Lancaster 1981), or assumed to correspond to arid episodes in global climate models (e.g. Sarnthein 1978). The development and increasingly widespread application of luminescence dating to aeolian quartz is now revolutionising the interpretation of arid aeolian landscapes.
8. *Relict aeolian units e.g. sand seas discussed below are not necessarily a record of simple aridity.* As research into the processes controlling aeolian activity develops, the analogues for interpreting relict Quaternary aeolian deposits and landforms improve (e.g. Kocurek 1998; Lancaster 1998). Models and past interpretations of simple arid/humid climate switches over simplify and miss some of the major interpretations. Aeolian deposits are not necessarily generated under arid conditions (though this is likely to be the case for most major Quaternary age dunefields) but depend on a package of antecedent conditions.

The points above highlight issues that have dogged palaeoenvironmental reconstructions of Pleistocene aridity. Perhaps it is the landform and sedimentary components that have been seen as most representative of arid episodes of the Quaternary (e.g. Sarnthein 1978). The opportunity for aeolian sediment accumulation is of course dependent upon the availability of suitable sediment for the development of aeolian accumulations, regardless of other antecedent conditions. Nonetheless, significant evidence pertains to this having been the case in many parts of the world, especially in low and sub-tropical latitudes, as demonstrated by the burgeoning literature detailing chronologies of aeolian accumulation in, for example many regions of Africa (e.g. Shaw 1997), central Australia (e.g. Croke 1997), North America (e.g. Tchakerian 1997), parts of central Asia (Derbyshire and Goudie 1997) and northwestern India (e.g. Wadhawan 1998). Issues relating to the extraction of palaeoenvironmental information from Quaternary aeolian systems will now be explored.

## Components of Arid/Aeolian Systems that Yield Valuable Records

### *Controls on Aeolian System Dynamics*

Within all aeolian systems the actual processes of deposition, leading to the accumulation of sediments that ultimately yield palaeoenvironmental records, depend on the nature of system controls. To this end three main system types can be identified from the investigation of modern aeolian processes and sediments (e.g. Kocurek 1988, 1998; Kocurek *et al.* 1991, Kocurek and Havholm 1994): wet, dry and stabilising systems. A wet system occurs when water table fluctuations control aeolian dynamics (see Fryberger *et al.* 1988) In terms of the development of deposits, accumulation occurs through the arrival of wind transported sediment at a damp, 'sticky' surface, for example a coastal sabkha. Without the damp surface, entrainment might continue, and no accumulation would result at the location concerned. In a dry system, aeolian behaviour and deposition are determined by aerodynamic conditions, including sufficient wind energy for transportation, surface roughness factors and the availability of suitable nuclei for deposition (e.g. Wilson 1972), and wind directional characteristics which affect the resultant dune form (Fryberger 1979). In stabilising systems surface factors such as vegetation control accumulation. Given that it is now recognised (see Livingstone and Thomas 1993, also below) that vegetation on dune surfaces is not automatically an indicator of dune system stability, this factor may have great significance in terms of deducing climatic change from the presence of stabilised dunes. Also significant is that, from a palaeoenvironmental perspective the principal controls affecting an individual aeolian system may change through time.

### *Sources of Palaeo-aeolian Environmental Data*

Two main categories of geomorphic systems and assemblages can be identified as key sources of palaeoenvironmental information about arid-aeolian regimes. Most research has to date focused on the information that may be gained from the investigation of the deposits within extensive *sand seas* (Fig. 1), which may be defined as dynamic sedimentary bodies that form part of local— and regional — scale sand transport systems? (Lancaster 1995). They generally cover an area of not less than 125 km$^2$ where no less than 20% (and usually considerably more) is covered by windblown sand (see Fryberger and Ahlbrandt 1979). Sand seas may be presently active or stabilised; the latter representing the extension of conditions conducive to aeolian activity (i.e. aridity) at the regional scale at times past. The largest continuous sand sea on earth is the Kalahari, covering approximately 2.5 million km$^2$ of central and southern Africa, mostly inactive in terms of aeolian processes under conditions prevailing today.

Also important, however, are more localised features that we may term here *'interactive systems'*. There are a range of different interactive systems, which can be defined as situations where aeolian deposits, landforms or erosional features have occurred in contemporaneous or subsequent association with another geomorphic process or feature, with some mutual interaction of processes or resultant deposits.

These include situations where *source bordering dunes* are formed as a result of aeolian deflation of fluvial sediments, for example the Great Sand Dunes in Colorado, formed from the deflation of sediments accumulated in a meander bend of the Colorado River, and in the Strzelecki-Simpson Desert, Australia (Wasson 1983) where linear dunes have deflated from dry river courses. In these situations, if the dunes do not extend far down wind from the source area, they may be more indicative of seasonal climate conditions and channel flow rather than regional aridity levels (see Williams 1985).

It is well documented that sediment deflated from pan or playa basins can form transverse or lunette sand dunes on the down wind margins of basins (e.g. Goudie and Wells 1995). Multiple dunes, perhaps with different orientations (e.g. Lancaster 1978) may yield useful evidence about successive deflational episodes. If geochemical evidence is extractable from the pan or playa sediments themselves, a composite record of humidity changes and deflational conditions may be extracted. The significance of the dunes themselves however, in terms of aridity, needs careful consideration however since controls on deflation may include factors such as seasonal water table fluctuations as well as aridity (Thomas *et al.* 1993; Shaw and Thomas 1997).

Sand ramps, interdigitated slope and aeolian deposits (Tchakerian 1991; Lancaster and Tchakerian 1996) have been identified as an important source of palaeoenvironmental conditions and regional sand transport in the Mojave Desert, California. Their wider identification in arid regions where hills and mountains are juxtaposed with source areas for aeolian and slope deposits suggests they may prove to be useful sources of interdigitated palaeoenvironmental data. Thomas *et al.* (1997a) have investigated a last-glacial age sand ramp in central Iran for its record of environmental change (Fig. 3).

## Key Issues in Establishing a Record

Having outlined the terrestrial systems that can be used to identify regional and local episodes of aridity and aeolian activity, it is important to consider developments that are increasing the utility of aeolian sediments and landforms as indicators of palaeoenvironmental change. This will be done by briefly examining recent research, conducted by investigators at the University of Sheffield and co-workers

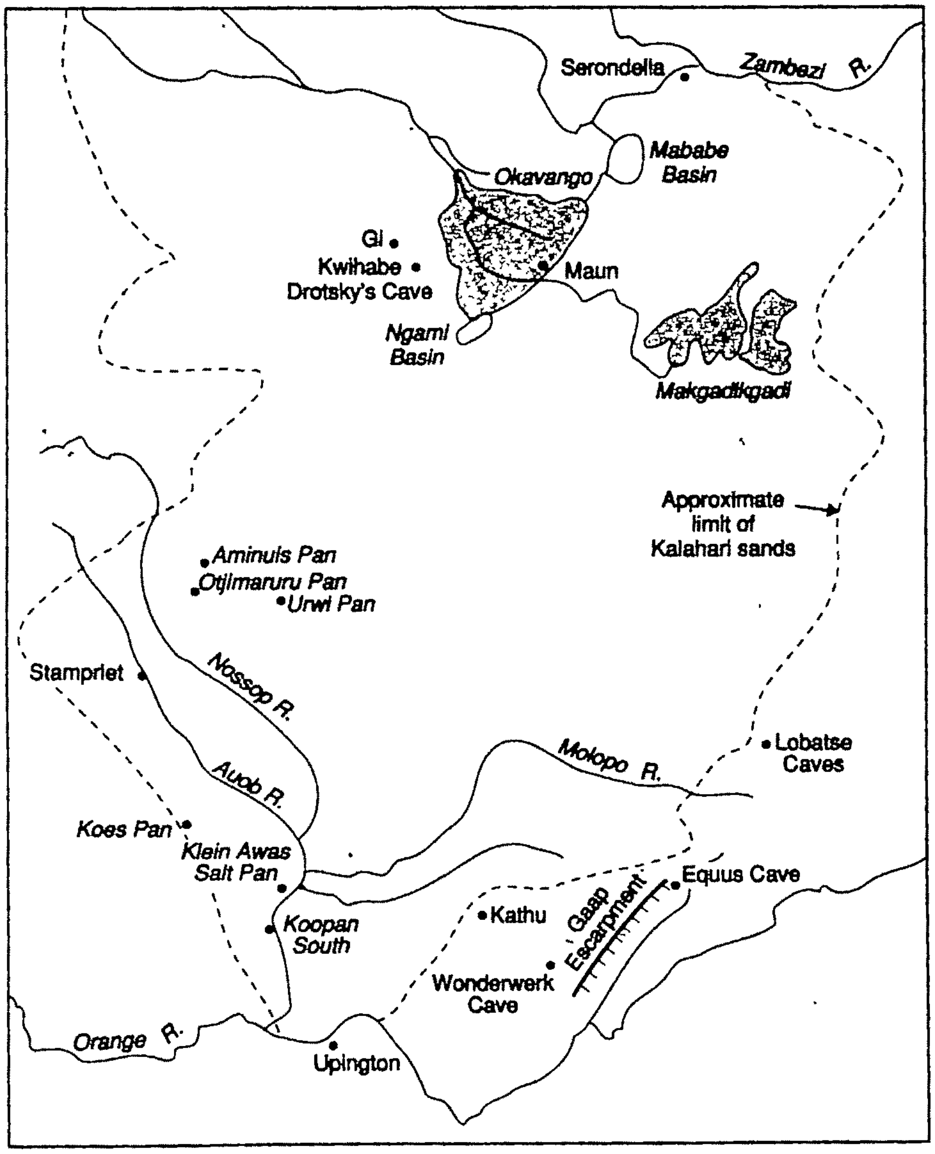

**Fig. 2**: Closed sites, on the periphery of the Kalahari, used in palaeoenvironmental studies (after Thomas and Shaw 1991a)

elsewhere, in the Kalahari sand sea of southern Africa. While this assessment is region-specific in the source of material upon which it draws, the finding and issues raised are of global utility.

*The Nature of and Controls on Dune Activity*

Dunes have been ascribed relict status using a number of criteria (see Thomas and Shaw 1991, Table 1). The presence of surface vegetation being one. In the Kalahari, three dunefields, dominated by linear dune forms, have been described as inactive and evidence of greater past aridity since Grove (1969) and Lancaster (1981). Figure 3 shows these dunefields, which have also (Lancaster 1981; Thomas 1984) been attributed to formation at different times and under different atmospheric circulation conditions.

Linear dunes however are not highly mobile dune forms, and develop through the process of extension and accretion rather than wholesale mobility (Thomas 1992). While dunes such as those in the northern Kalahari (e.g. Flint and Bond 1968) have a well developed woodland cover and are clearly degraded, those in the southwest Kalahari (which is today arid to semi-arid with a mean annual rainfall of 150-200 mm), whilst not displaying extensive aeolian activity today, possess a partial vegetation cover, particularly of perennial and annual grasses.

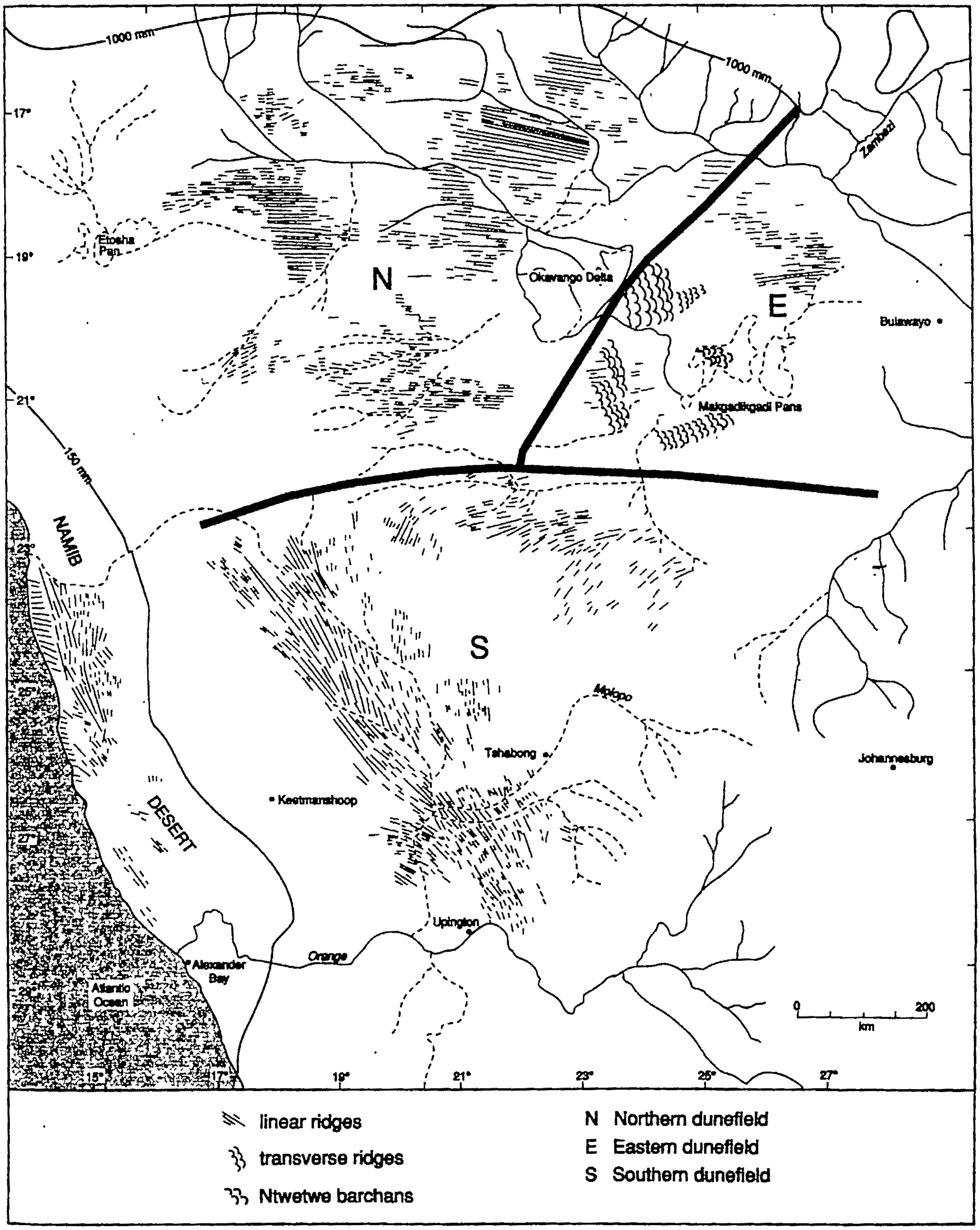

Fig 3. Dunefields in the Kalahari, dominated by linear forms. Note the division into three systems, assumed to be of different age, and the distribution of dunes compared to closed sites in Figure 2.

**Table 1**: Criteria used to designate 'relict status' to desert dunes (after Thomas and Shaw 1991b)

| Criterion | Location |
|---|---|
| *Morphological* | |
| Reduction in dune height | Zimbabwe |
| Reduction in slope angles | Zimbabwe |
| Gullying of dune surfaces | Niger |
| Dunes degraded and drowned in lake sediments | Botswana |
| Dunes drowned in coastal sediments | Australia |
| Linear microridges in sandy sediments | Zaire |
| *Sedimentological* | |
| Absence of systematic dune profile particle size patterns | Zimbabwe |
| High silt and clay percentage | India |
| Dune surface soil development | U.S.A. |
| *Biological* | |
| Presence of dune surface woodland | Zaire |
| Presence of savanna grasses | Botswana |
| Presence of surface algal crust | Niger |

Although the southwest Kalahari dunes have been widely regarded as fossil forms, and have been considered to be the result of late-Pleistocene/early Holocene enhanced aridity, process studies by Wiggs *et al.* (1995, 1996), and analysis of decadal-scale data on climatic conditions (rainfall, potential evapotranspiration, wind strengths, wind directional characteristics) by Bullard *et al.* (1996, 1997), dictate a more complex situation in terms of the controls upon dune activity and dune activity status. Ash and Wasson (1983), through investigations of surface processes on Australian linear dunes, showed that sand transport can occur on dune surfaces with up to about 30% vegetation cover. Wiggs *et al.* (1995) identified a gradient of activity operating across linear dune profiles in the southwest Kalahari. In interdune areas and on lower dune slopes, under present conditions, it is not vegetation cover, but available wind energy, that is the primary inhibitor of sand transport. In other words, even if these surfaces were vegetation free, present day wind energy is insufficient to transport significant volumes of sand. On upper dune slopes and dune crests, where speed-up effects give rise to higher wind velocities, vegetation cover densities impact most importantly on sand transport. Thus dunes with differing degrees of vegetation cover vary in their surface activity, with a cover threshold of about 14% for the total cessation of sand transport (Wiggs *et al.* 1995).

The investigations leading to the above findings were conducted in 1991-92. To extend the picture further, Bullard *et al.* (1996, 1997) modelled longer term trends for climate station-locations within the southern Kalahari by applying climate data to a dune mobility (or activity) index (Lancaster 1988) that effectively assessed dune erosivity (vegetation cover, influenced by P/PE) and erodability (a measure of wind energy above the entrainment threshold). Over a thirty year period, 1960-1990, sand transport potential varied markedly, with modelled activity high during the 1980s, with projected full dune surface activity, and particularly low in the mid 1970s (Bullard *et al.* 1997; Fig. 4). Analysis of potential sand transport directional trends during the same period (Bullard *et al.* 1996), using the 'Fryberger equation' (Fryberger 1979), identified significant directional variability from season to season and between years. This variation is perhaps too great for linear dune construction, but given the low overall transport energy today is not sufficient to break up the linear dune pattern.

These studies of the modern southwest Kalahari linear dune environment have important implications for the interpretation of dune 'activity' and in interpreting the dunefield in a palaeoenvironmental context. In particular:

- there is key interplay between erodibility and erosivity.
- present day climate: dune relationships suggest that the SW Kalahari dunefield was emplaced when regional winds were stronger and more consistent in direction.
- rainfall may have been lower but need not have been if winds were stronger as PET would have been greater, reducing vegetation growth potential.
- however, the present day high temporal variability in precipitation may be unrepresentative of dune building

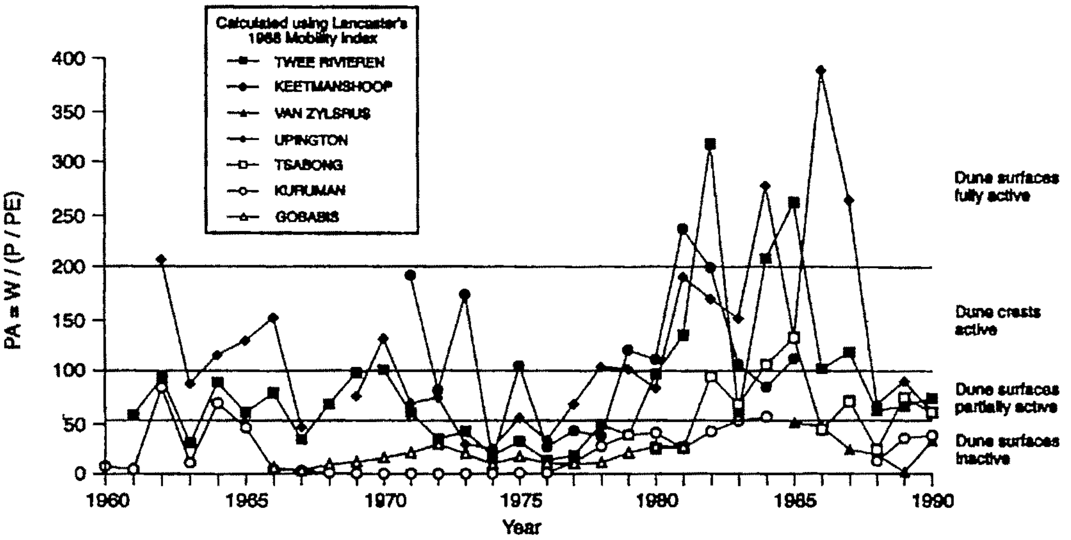

Fig. 4. Temporal trends in dunefield activity, in the southwest Kalahari, modelled from climate data using a dune activity index (after Bullard *et al.* 1996)

conditions when more constantly low conditions may well have prevailed.

- dunefield pattern complexity (with crossing and merging linear forms: Bullard *et al.* 1994) may indicate localised reworking of parts of the dunefield at times since major emplacement.

Livingstone and Thomas (1993) concluded that different states of dune activity exist. While significant sand activity and accumulation is necessary for dune formation, which is probably indicative of deep aridity with accompanying windiness, surface activity and dune form maintenance can occur with lower wind velocities (or under conditions of marked temporal variability) and reduced erodibility. The crestal surfaces of southwest Kalahari linear dunes today are mantled by a few centimetres to 1 m of unconsolidated sand. This is the component that responds to present day activity opportunities. The cores of the linear dunes are more consolidated. These represent the phase or phases of dune construction. If climate today were to move towards a situation more conducive to dune construction, the upper unconsolidated sand, and perhaps parts of the core, would be susceptible to reworking and redeposition. Thus it is extremely likely that the dunes preserved as relict forms, and the cores or present day dunes in the southwest Kalahari are features derived from more arid time/times in the past.

### *Producing a Chronology*

The application of luminescence dating (see Aitken 1992, 1998), and others for details of techniques) to sediments derived from dunes in the Kalahari is leading to a better understanding of the timing of dune construction and aridity in the region. Earlier work suggested, in the absence of direct chronometric applications to dune sands, that each of the three linear dune systems in the Kalahari had formed at a different time, with the time of development assumed from gaps within the humid chronology. For example, the northern dunes (Fig. 3) were given an age older than 30,000 BP, the eastern dunes were considered coincident with the last glacial maximum and the southern dunes as of late Pleistocene-early Holocene age (e.g. Lancaster 1981).

Systematic sampling for the application of optical dating, was commenced in 1991 and continues today. To date over 200 samples have been collected from a range of stratigraphic contexts within the aeolian systems, principally from linear dune cores but also including lunette dunes, marginal sand sheets and smaller dune forms crossing or superimposed upon the linear dunes. Stokes *et al.* (1997a and 1997b,1998), Thomas *et al.* (1997, 1998) and O'Connor and Thomas (in press) have presented the first phase of results (Fig. 5). Significantly, these demonstrate a more complex history of aeolian activity and aridity than initially proposed by Lancaster (1981) and others. In the context of the aims of this paper it is most pertinent to note that at least four periods of dune construction, at c. 115-95,000 ka, 46-41,000 ka, 26-20,000 and 16-9,000 ka are identified. Older individual ages, back to c. 160,000 ka, have been obtained (Stokes *et al.* 1997b) but presently have not been replicated and therefore are not yet regarded with certainty as representing major constructional phases. Localised reworking, in the form of hummocky dunes and crossing dunes (Thomas *et al.* 1997) occurred on at least two occasions in the Holocene, at c. 5,000 ka and 1-2,000 ka.

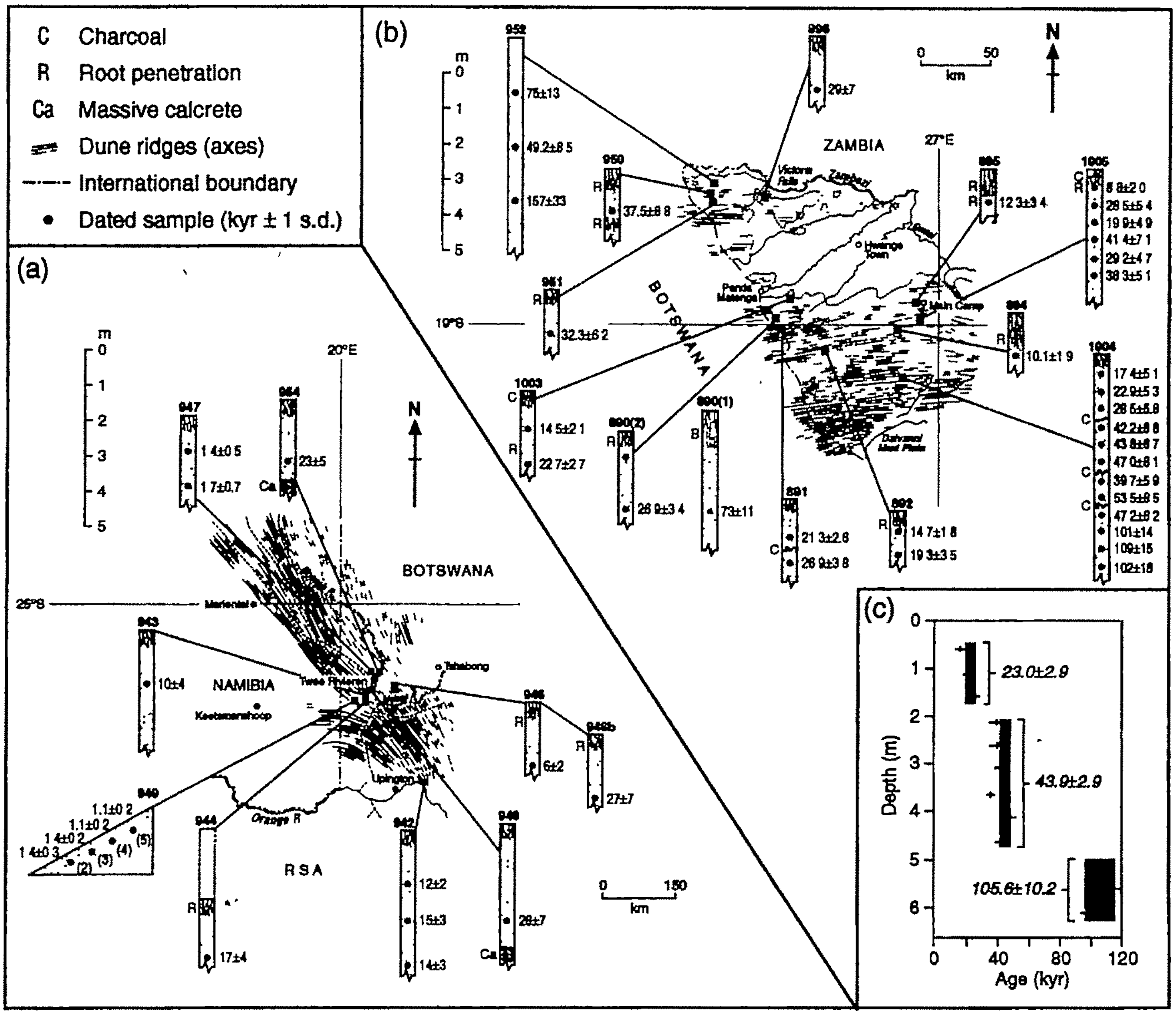

Fig. 5: Sample sites, and optical ages of sand deposition, in a) the southern Kalahari and b) the eastern Kalahari (after Stokes *et al.* 1997b)

The last two appear to be Kalahari-wide, preserved in the linear dune forms of all three main dune areas. The older periods are not identified in the southern Kalahari dunes, probably because this is a sediment supply-starved area (Thomas *et al.* 1997) when compared with more northerly areas, such that dunes constructed in earlier phases have been consumed and reworked in later ones. Where sand supply is greater, including in dunefields within or adjacent to major fluvial systems, the availability of new sediment for deflation at the onset of arid periods may allow older deposits to be built upon and preserved.

## Conclusion

Through the application of the outcome of process studies, and the application of directly applied chronometric techniques, it is now becoming possible to determine, rather than infer, the nature and timing of late Quaternary aridity. It is extremely likely that, as investigations progress, present assessments will be reassessed, refined and revised. What is clear is the potential of aeolian systems to directly contribute to palaeoenvironmental reconstructions of Pleistocene environmental and climatic changes. A range of aeolian-system data sources exist, and though their occurrence and preservation is not equal across the world's sand seas and drylands, they offer a real opportunity for testing, and challenging, previous simple models of the timing and distribution of Quaternary aridity across the globe.

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# Luminescence Dating Results of Dune Profiles from the Margins of the Thar Desert and their Implications

M.P. Chougaonkar, K.S. Raghav[1], S.N. Rajaguru[2], A. Kar[3], A.K. Singhvi[4] and K.S.V. Nambi[5]

Environmental Assessment Division
Bhabha Atomic Research Centre
Mumbai 400 085

1 Environmental Geological Division
Geological Survey of India
Jaipur 342 015

2 Deccan College
Pune 411 007

3 Central Arid Zone Research Institute
Jodhpur 342 003

4 Earth Sciences Division
Physical Research Laboratory
Ahmedabad 380 009

5 101, Janmotri, Sector 7
Kopar Khairane
Navi Mumbai 400 709

## Abstract

IRSL (Infrared Simulated Luminescence) dating of two sand dune profiles on the eastern margin of the Thar using a 950 nm stimulation band indicates three distinct phases of aeolian accumulation centred at 65 kyr, 32 kyr and 16-10 kyr. These are in conformity with the regional data on the climatic record of the Thar and show that the Thar desert is not of anthropogenic origin nor is there any significant eastward advance.

## Introduction

The sedimentary records from the margins of the Thar desert hold the potential for understanding the periods of expansion and contraction of the Thar during the past, and also for palaeoenvironmental/palaeomonsoonal reconstruction. Aeolian sand and fossil dunes in this region indicate changes in climatic conditions during the past. A dune shift of 350 km was estimated by Goudie *et al.* (1973). The aeolian sequences along the eastern margin (450 mm/year annual precipitation) show multiple phases of sand accretion and quiescence, as indicated by sands intercalated with pedogenesis and calcrete formation. As part of a coordinated programme on understanding the timing and duration of past episodes of expansion and contraction of the Thar desert and their relationship to monsoon conditions (e.g. Thomas *et al.* 1999), two profiles were dug at Amarsar (27° 22' 57" N; 75° 49' 26" E and 27° 21' 72" N; 75° 50' 52" E), District Jaipur, Rajasthan (Fig. 1). These profiles are termed Amarsar I and Amarsar II, respectively. The Amarsar sequence occurs in large areas of the Jaipur Upland within the Aravalli hill ranges (Raghav 1992). Amarsar I is a profile in a deep sandy plain presently dissected by a gully network. Amarsar II is a 5 m deep profile in a low sand dune which is also gullied. The exposed sequence here suggests a more varied history than Amarsar I.

## Stratigraphic Details (Fig. 2)

*Amarsar I*: The exposed ~7 m section at Amarsar I reveals at least three major sedimentary units corresponding to periods of sand accretion and surface stabilization. The uppermost 2 m (Unit 1) consists of an aeolian sand sheet deposit which has undergone minor pedogenesis and leaching. The first 1 m of this has a reddish brown fine sand with moderate sorting and no carbonates. Concentration of carbonates increases down the profile and the sediment colour changes from light yellow brown to grey yellow. The underlying second unit (Unit 2) between 2 m and 5.6 m depth has a leached sand horizon, followed by a 10 cm thick sand-silt dominated layer. The remainder of the unit consists of thicker zones (60-90 cm) of less nodular, yellowish to greyish sand and silt layers alternating with thinner zones (~20 cm) with more concentrated hard nodular carbonates in the sand and silt. The basal part of the unit is characterised by ~1 m thick, less compact greyish sand with moderate sorting and with almost no carbonate nodules. The oldest exposed unit (Unit 3) in this section is a light brown, medium to fine sand with good sorting and diffused carbonates but with no nodules. It occurs between 5.6 and >7 m depth.

*Amarsar II*: This is a 5 m deep profile in a low sand dune that has been cut across by a gully. Unit 1 here has the top 1 m comprising moderately sorted, greyish medium to fine sand with a few small soft nodular carbonates. This is followed by a poorly sorted, greyish fine sand horizon with ~5-10% areal spread of small carbonate nodules. Overall Unit 1 at Amarsar I and II are comparable. Unit 2 begins with a ~10 cm thick greyish brown, moderate to poorly

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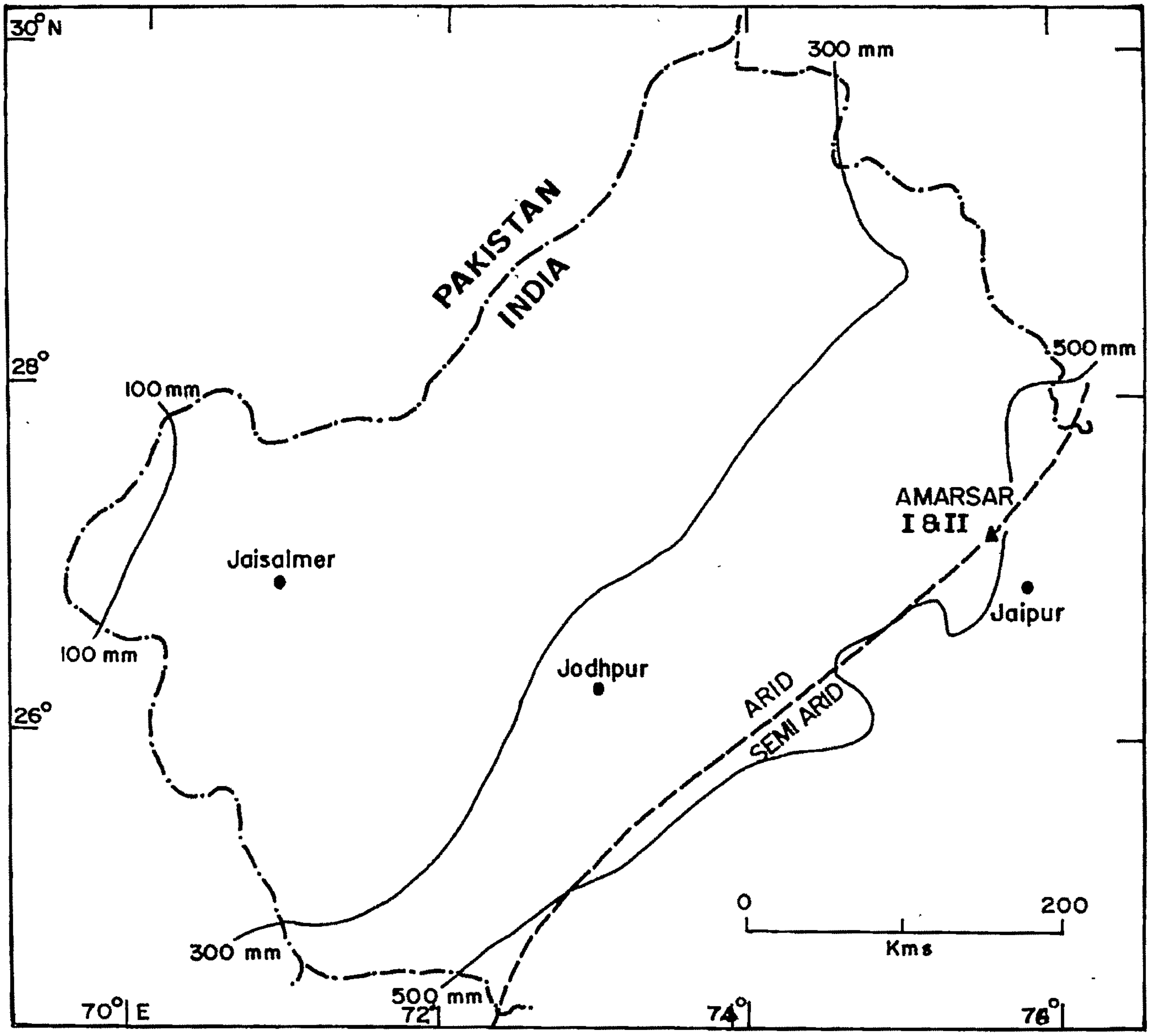

**Fig. 1**: Location map of Amarsar

sorted fine sand horizon. Below it a 3 m zone consists of greyish brown to reddish brown, mottled medium to fine sand with moderate sorting for the upper 1.5 m, and this is gradually replaced by yellowish brown aeolian sand beneath. Carbonate nodules increase in size and concentration down the profile in this unit and have a bedded appearance which, along with the mottled nature of the host sediments, suggests groundwater as a primary source for their formation. Altogether the varied nature of sediments, carbonates and textural changes suggest that these sands have a long record of aeolian accumulation.

## Luminescence Dating

The basic principles of luminescence dating of sands are well established (Aitken 1985, 1998; Singhvi *et al.* 1982). The method works on the premise that daylight exposure during the sand transport efficiently photobleaches the pre-existing geological luminescence to a near zero residual value. On burial further sun exposure ceases and a fresh accumulation of luminescence is initiated due to radiation exposure from ambient radioactivity viz. U, Th and K with a minor but finite contribution by cosmic rays. In view of easy photobleachability, only the most recent depositional

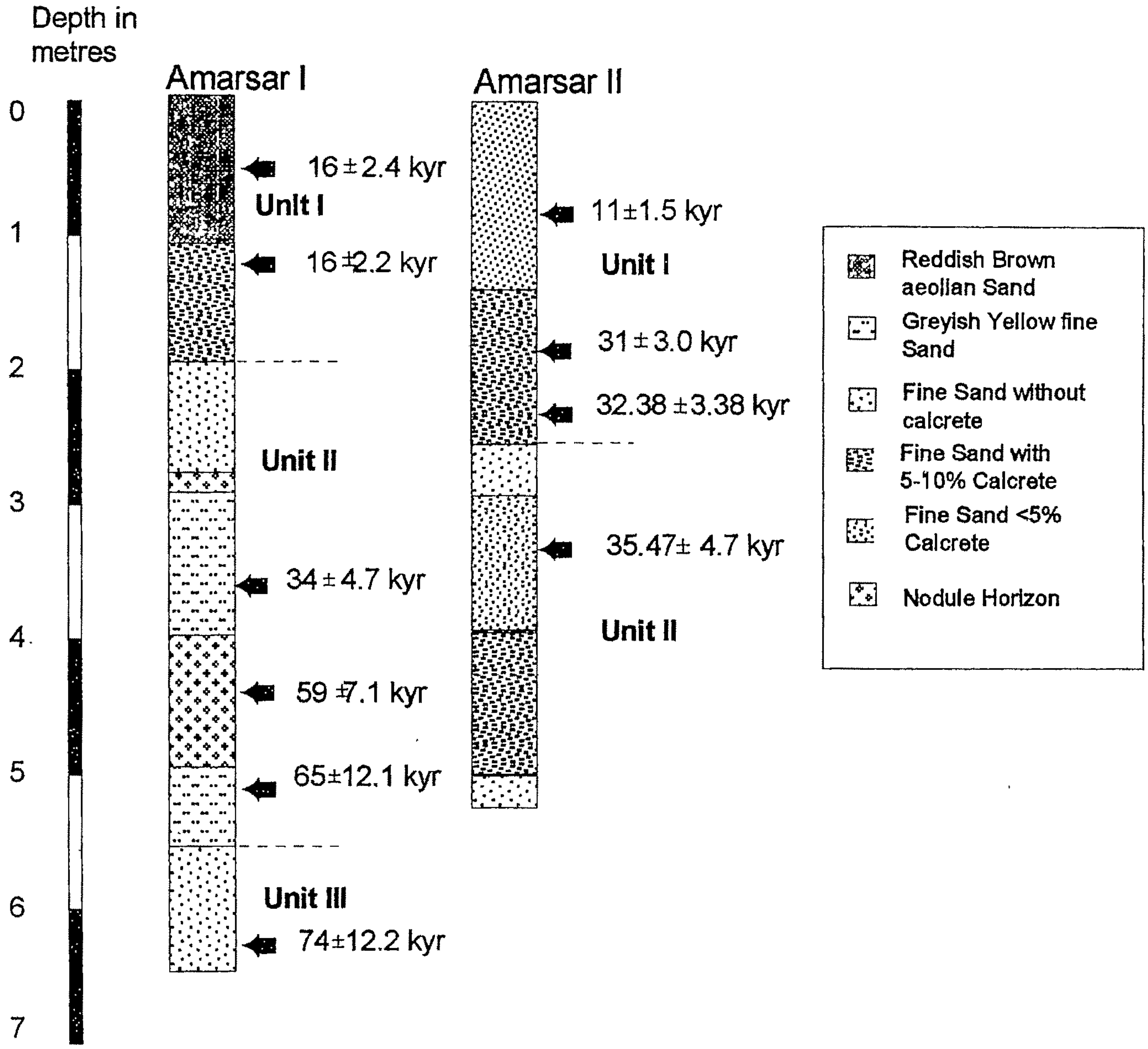

**Fig. 2**: Profile of the Amarsar sequence, heights adjusted with the help of calcrete horizons

events are dated by the technique. The age is given by a deceptively simple equation:

**Age (years) = Luminescence acquired since burial/ Annual rate of luminescence acquisition**

Since luminescence is acquired by radiation, it is convenient to work in radiation units and the age equation is rewritten as:

**Age = Palaeodose (P; Gy)/Annual dose ($D_T$; Gy/kyrs)**

The palaeodose P is the laboratory radiation dose (expressed in radiation dose units, Gy) that induces in the sample the same level of luminescence as exists in a natural sample. Generally the ages are measured by using either thermal stimulation by heating the sample up to 400-500° C (thermoluminescence) or green light stimulation (GLSL) by stimulating the sample by green or blue green light (450-540 nm) or the infrared light stimulation (IRSL) using 880 nm infrared light. As a small variant in the present study 950 nm light was used for stimulation of the samples. While considerable effort has been made on the use of 880 nm, the present study is perhaps the first dating programme based on this stimulation wave-length, though some reports discuss studies with this wavelength

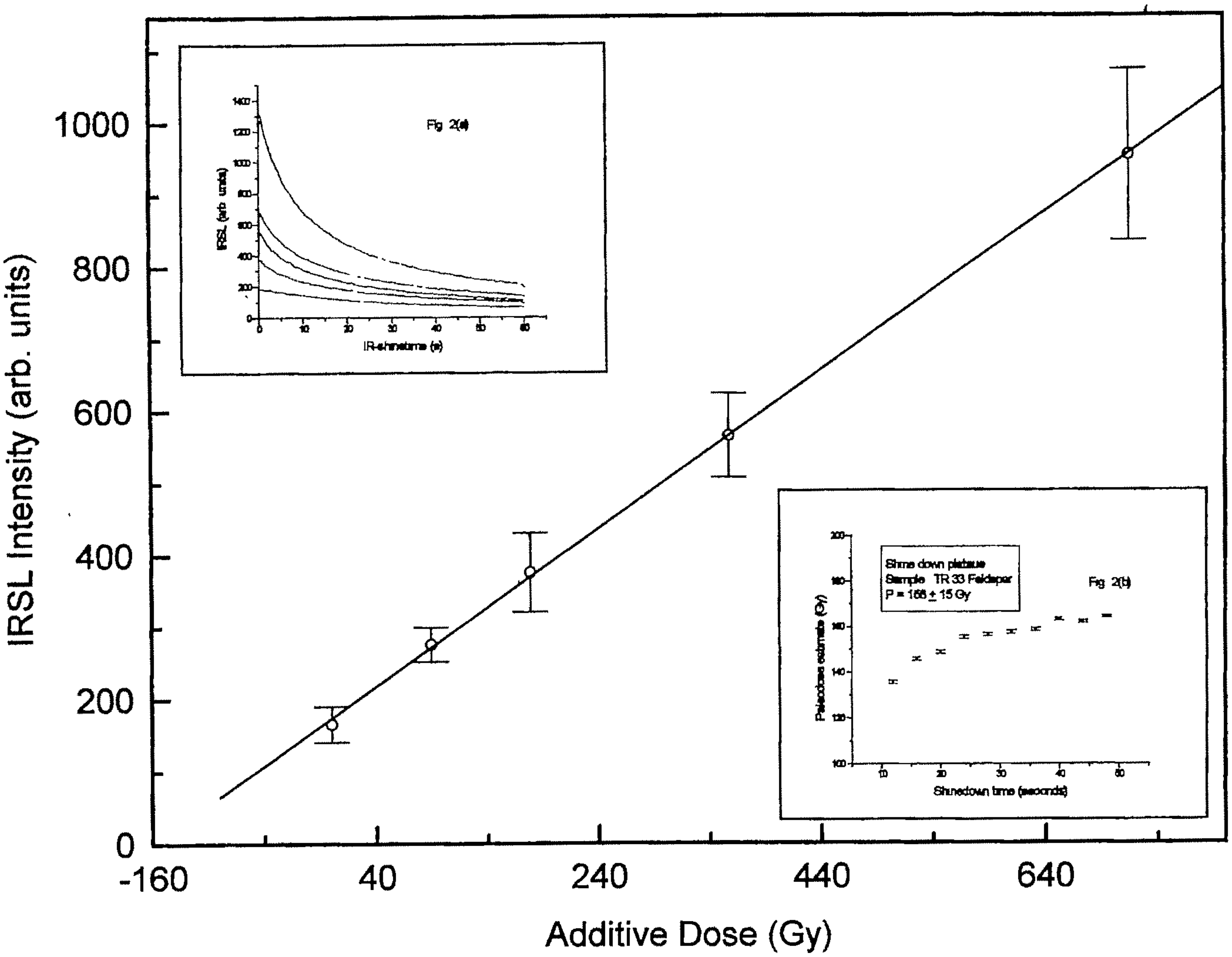

**Fig. 3**: Typical growth curve for determination for palaeodose P received by sample TR 33 by additive dose method

(e.g. Galloway 1994; Bailiff and Poolton 1991). This was done after our studies with comparison of IR stimulation wavelengths viz. 880 and 950 nm (the only IR LEDs available locally) which indicated that there is no difference in the nature of IRSL shinedown curves except that IRSL produced by 950 nm stimulation was much greater than by 880 nm.

The dating analysis was carried out by using 100-200 μm K-feldspar mineral separates from the sands. These were extracted by using standard physio-chemical techniques involving IN HCl, $H_2O_2$ sieving and heavy liquid separation using sodium polytungstate. IRSL measurements were carried out using an indigenously developed IRSL reader using Telefunken TSUS 5402 IR LEDs (Chougaonkar *et al.* 1996) for stimulation. The detection optics comprised an EMI 9635 QB photomultiplier tube with a Schott band pass filter (405 ± 11 nm) and a Chance Pilkington HA3 infra red cut off filter to reduce the IR interference in IRSL. IRSL measurements were carried out using DC amplifier coupled to PC based analyser developed for the purpose. Laboratory irradiations were carried out using 90 Sr/90Y beta source (5.96 gy/min). Annual doses ($D_T$) were estimated from the radioactivity assay obtained by thick source alpha counting with pairs unit (Chougaonkar *et al.* 1999) (Th and U) and atomic absorption spectrometry (K). The decay series of U and Th were assumed to be in radioactive equilibrium.

The palaeodose was estimated using the additive dose procedure and this was done after 'late light subtraction' as suggested by Aitken and Xie (1992). All the discs were normalized using a 1s short shine on natural discs.

Table 1: Concentrations of radioactive elements in different samples, evaluated dose rates, estimated palaeodose and ages

| Sample Code, Depth (m) | Concentrations Th (ppm) | U (ppm) | K (%) | Total Annual Dose Rate (Gy/kyr) | Estimated Palaeodose P (Gy) | Age (kyr) |
|---|---|---|---|---|---|---|
| Amarsar I | | | | | | |
| Tr 27 (0.50) | 11.31±2.08 | 2.57±0.61 | 1.14±0.15 | 2.74±0.46 | 43.1±2.7 | 16±2.4 |
| Tr 28 (1.09) | 13.67±2.22 | 3.14±0.65 | 1.04±0.01 | 2.98±0.36 | 47.9±5.3 | 16±2.2 |
| Tr 32 (3.53) | 7.04±1.92 | 3.67±0.56 | 1.09±0.05 | 2.63±0.34 | 88.9±9.4 | 34±4.7 |
| Tr 33 (4.42) | 14.36±1.81 | 1.93±0.53 | 1.01±0.08 | 2.69±0.30 | 158.0±15.0 | 59±7.1 |
| Tr 34 (5.02) | 14.45±1.91 | 1.76±0.56 | 0.76±0.03 | 2.45±0.33 | 159.5±28.5 | 66±12.1 |
| Tr 36 (6.42) | 12.99±1.55 | 0.97±0.45 | 0.97±0.04 | 2.30±0.28 | 171.1±26.6 | 75±12.2 |
| Amarsar II | | | | | | |
| Tr 37 (0.70) | 11.07±1.73 | 2.44±0.51 | 0.95±0.03 | 2.52±0.29 | 26.5±3.6 | 11±1.5 |
| Tr 38 (1.70) | 24.11±2.18 | 1.79±0.64 | 0.93±0.01 | 3.38±0.35 | 102.6±6.0 | 31±3.0 |
| Tr 39 (2.20) | 17.87±1.88 | 1.15±0.55 | 0.98±0.02 | 2.75±0.31 | 86.6±7.7 | 32±3.8 |
| Tr 40 (3.20) | 11.4±1.94 | 2.86±0.57 | 1 01±0 03 | 2.71±0.32 | 93.2±10.8 | 35±4.7 |

## Results and Discussion

Table 1 provides the radioactivity and the palaeodose data on the samples. Figure 2 provides typical shine down curves, growth curves and the shine plateau. It is of interest to notice that all the samples indicated a linear growth curve dispite the fact the total dose (natural + maximum beta) in them was upto 500 Gy. This needs scrutiny because, should this be established, this may provide a better alternative to 880 nm stimulation for an increased precision in the ages. To check the stability of the signal, while isothermal annealing experiments are in progress, a sample was analysed using thermoluminescence and the results were concordant.

The dates on the samples suggest that at Amarsar I Unit 3 was formed at ~75 kyr. Unit 2 was deposited between 59 and 34 kyr. This unit has several pedogenic features which suggest humid episodes in a semi-arid domain. Two samples in Unit 1 indicate a phase of sand accretion beginning at 16 kyr. At Amarsar II sand accretion in Unit 2 took place ~32 kyr. Unit I has an age of 11 kyr. The following deductions can be made from the dates.

1. The aeolian activity here dates back to >75 kyr (only a part of the sequence could be exposed at Amarsar II).
2. The aeolian activity occurred at accelerated paces at 65 kyr, 32 kyr and during 16-11 kyr.
3. Ages of 11 kyr (Amarsar II) and 16 kyr (Amarsar I) in the uppermost part of both the profiles suggest that the last major episode of sand accretion preceded the Holocene.

The overall records parallel the aeolian record of the Thar desert (Thomas *et al.* 1999). Recent studies at a site in the central Thar (Shergarh Tri-Junction) indicated periods of aridity at 65 kyr and 30 kyr (Andrews *et al.* 1998) which parallel the increased aeolian activities at Amasar. The increased aeolian accumulation during the period 16-11 kyr has also been documented in the Thar previously (Chawla *et al.* 1992) and this is considered to be connected to the winds provided by the onset of the SW monsoon. The study also documents a more humid phase during 59-33 kyr when sand accretion gave way to pedogenic proccesses. It is of interest to mention here that the record from the Thar desert seems to agree with the overall record of monsoon reconstruction (Prell and Kutzbach 1987), and the fact that geomorphic processes are accelerated during periods of climatic transition. The study also disproves the convention concept of the anthropogenic origin of the Thar, as also the claims of its eastward advance (Dhabariya 1987). Methodologically, the overall concordance with other results from the region indicates that the 950 nm IRSL.may provide an attractive alternative to 880 nm on account of a greater range of linear growth.

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# Late Holocene Environment and Culture at Bari Bavri, Western Rajasthan, India

Deotare B.C., M.D. Kajale, Sheela Kusumgar[1] and S.N. Rajaguru

Department of Archaeology
Deccan College
Pune 411 006

1 Physical Research Laboratory
Ahmedabad 320 009

## Abstract

The paper deals with the cultural and environmental interpretation of an archaeological site dating to around 500 A.D., preserved under a pebbly-sandy gravel within a wide channel. The archaeological material has been preserved by the armouring effect of the covering gravel, which could not be transported by later floods. This is a typical desert flood deposit of an ephemeral stream near Bari Bavri, emanating from the arid core of Jodhpur District, western Rajasthan. The multidisciplinary approach involving geoarchaeology, palaeobotany, radiocarbon dating, stratigraphy and chemical studies have enabled us to attempt a palaeoenvironmental interpretation of the hitherto less well studied Late Holocene palaeoclimatic history of parts of the Thar desert.

## Introduction

Multidisciplinary approaches to Quaternary studies, involving geology, geomorphology, geochemistry (including stable isotopes), geochronology, Quaternary palynology and prehistoric archaeology have, in the last 20 years, advanced our knowledge on chronology, environmental changes and cultural growth as well as deterioration in the arid and semi-arid parts of western Rajasthan The antiquity of early man in this region goes back at least to the early Late Pleistocene (Allchin *et al.* 1978; Misra and Rajaguru 1987; Deotare *et al.* 1998). Recently Kar *et al.* (1999) and Andrew *et al.* (1998) have studied the geochronology and palaeoclimate of aeolian sands in the southwestern part of the Thar desert. On the basis of such studies and our own archaeological observations in this area it appears that there is relatively better development of culture around 100 kyr, 30-40 kyr, 9-5 kyr, 2 5-1.3 kyr and probably between 0.9 kyr and 0.7 kyr. On the other hand, a decline in cultural development is seen around 20-16 kyr, 4-2.5 kyr, 1.4-1 kyr. Recently Sharma (1987) and Dhavalikar (1999), a historian and archaeologist respectively, have assessed the available historical, archaeological, literary evidence (including travellers accounts) for the protohistoric and Early Historic periods in India and have strongly argued in favour of a decline in urban culture particularly in western and southern India between the 4th and the 10th century A.D. This period has been labelled as 'Dark Age' in Europe (von Rad *et al.* 1999) and had been correlated with climatic deterioration. Dhavalikar has suggested that urban decline in India may have been due to the weakening of the summer monsoon and increased cold in Europe and higher latitude regions. Though Dhavalikar has not been able to cite any authentic physical and biological data in support of his hypothesis, he has indirectly tried to find a relationship between weakened summer monsoons of western India with the Ethiopian upland rainfall in northeastern Africa from where the river Nile originates. Dhavalikar has cited Bell's (1970) study on the history of floods in the Nile during the mid to late Holocene.

During our recent multidisciplinary investigations around Bap-Malar in the western part of Jodhpur District, we discovered historical sites in the context of alluvial deposits which help us to understand the culture-environment relationship around 500 A.D. in the present arid parts of western Rajasthan.

## Study Area

The Bap-Malar playa (72° 22' to 72° 27'E and 27° 15' to 27° 24' N) occurs in the western arid part of Jodhpur District where the present mean annual rainfall is around 200-250 mm and annual evaporation is around 2000 mm. About 80% of annual rainfall occurs during the summer months of July, August and September.

Bap-Malar playa is a shallow erosional depression developed in the pediment surface formed over the Permo-Carboniferous Bap-Boulder bed and Mesozoic sediments dominated by sandstone, claystone, conglomerate and varieties of limestone. The playa is not older than the Terminal Pleistocene and has probably formed due to Late Quaternary tectonics and climatic changes (Deotare *et al.*

1998; Kajale *et al.* 1999). Our detailed geoarchaeological and palynological studies of subsurface sediments (up to a depth of 7 m) and of surrounding dunes and sandsheets and also ephemeral streams probably feeding into the playa have brought interesting data on Late Quaternary environmental and human cultural changes in this area. Further, it has been observed that the region has been occupied by man since the early Late Pleistocene when the area had a better integrated bedrock channel system as compared to today's. The Lower and Middle Palaeolithic sites occur in regolith capping the rocky pediments. These studies show that the region is dominated by pediments which are covered by ferricretes and calcretes of Neogene and Early Quaternary age. A large number of microlithic scatters are found on the stabilised biocrusted surface of sand dunes and sandsheets of Late Pleistocene age. We also found non-diagnostic pottery along with the microliths but have not been able to establish its exact relationship of the

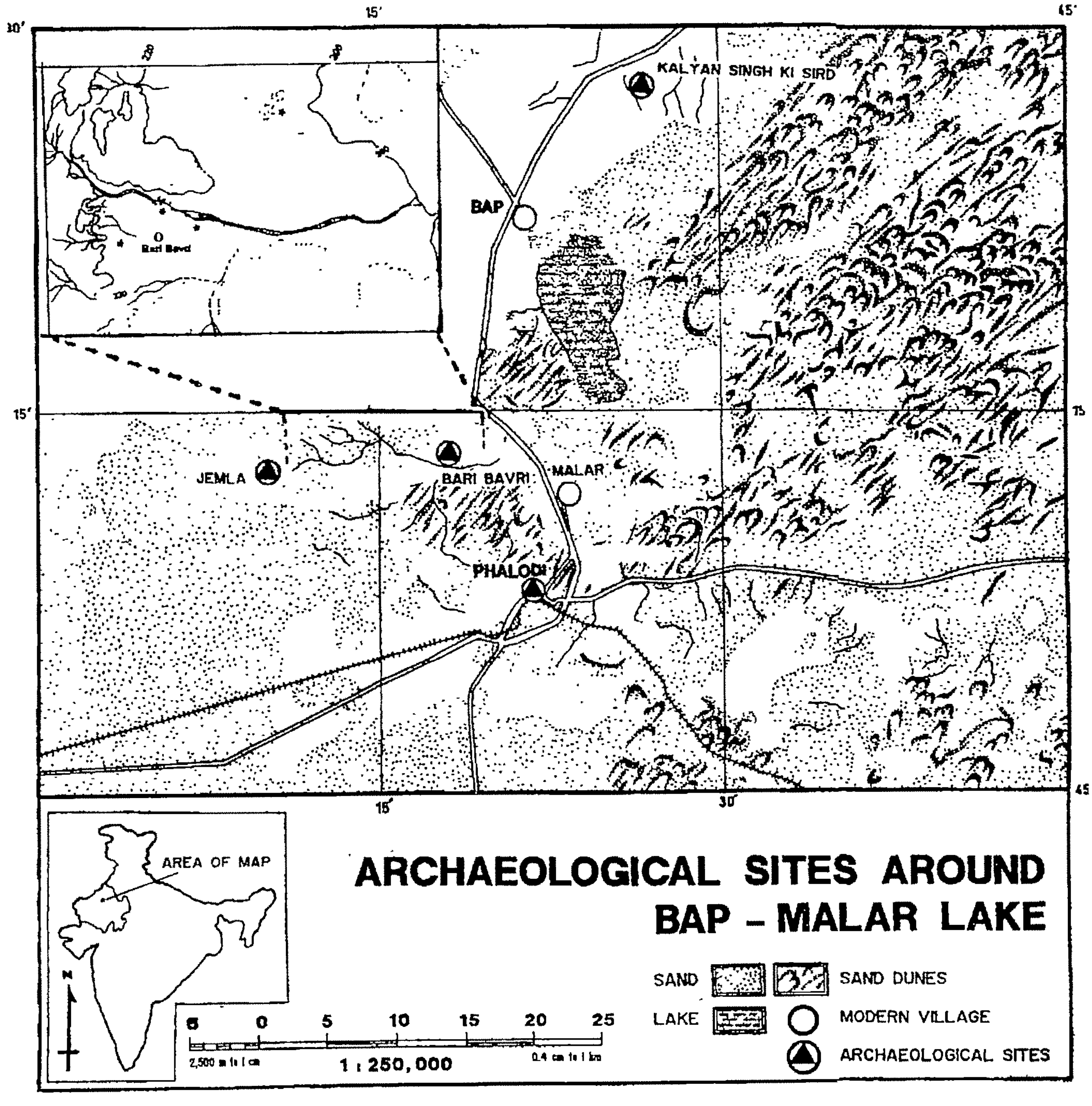

**Fig. 1:** Map of archaeological sites around Bap-Malar

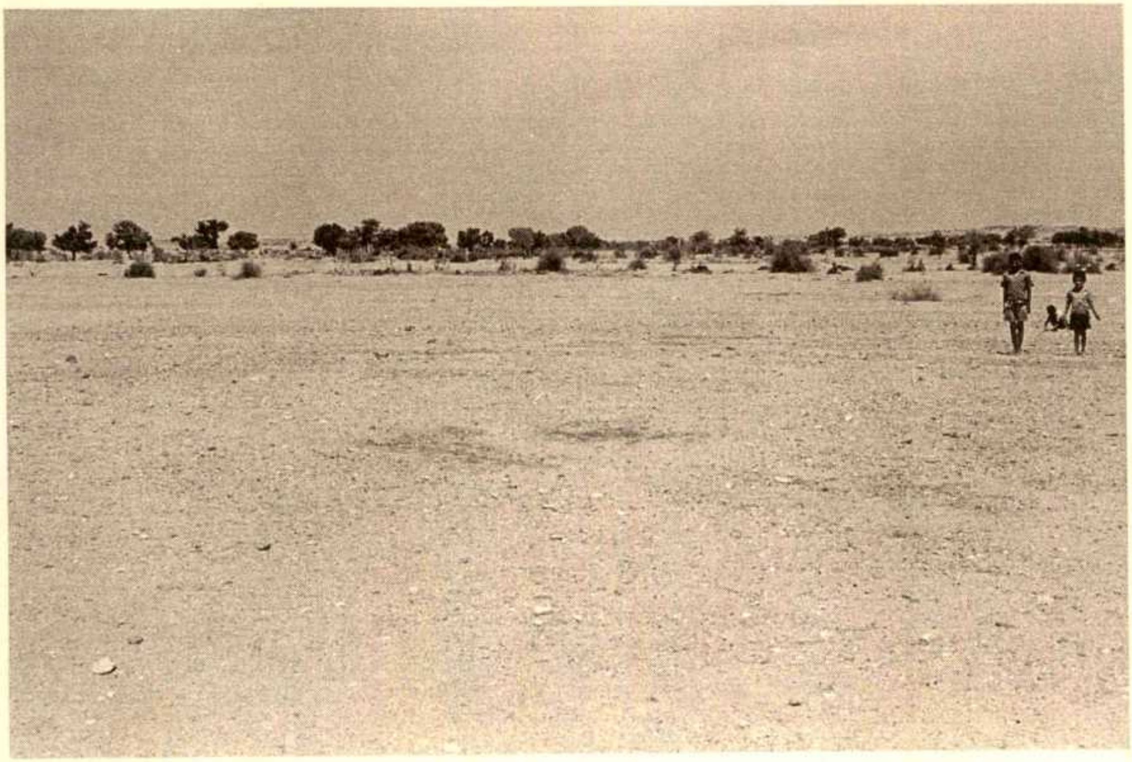

**Fig. 2**: Pebbly sandy channel gravel with pottery and other antiquity at Bari Bavri

pottery with the microliths due to the lack of precise stratigraphical and geochronological data. Tentatively, the microlithic scatters have been dated to the Early Holocene when the playa was perennial due to climatic amelioration. The Bap-Malar playa (Kajale and Deotare 1997) as also other shallow playas like Lunkaransar (Enzel *et al.* 1999) on the western margin of the Thar desert dried up around 5.5 to 5 kyr (Deotare *et al.* 1998; Enzel *et al.* 1999) while the Didwana lake on the eastern side of western Rajasthan continued to hold water until around 4 kyr (Singh *et al.* 1974; Wasson *et al.* 1983). Since none of these lakes have absolute chronologies post-dating 4 kyr, it is somewhat difficult to reconstruct environmental changes during the Late Holocene (c. post 3000 B.P.) due to lack of sensitive and reliable geomorphological and biological parameters. Though historical sites have been reported in the northern and eastern part of Rajasthan (Dhavalikar 1999), so far no sites of the historical period have been reported from the arid core of the Thar desert. Hence our discovery of interesting archaeological materials in the sandy gravelly channels of ephemeral streams draining into the surrounding area of Bap-Malar playa is significant. For the first time, we are trying to demonstrate environmental aspects during historical times along the arid western margin of the Thar desert.

## Archaeological Findings

Two important historical sites, one at Bari Bavri and the other at Kalyan Singh ki Sird, were discovered around the Bap-Malar playa. The site of Bari Bavri (72° 13' E and 27° 16' N) is located about 10 km northwest of Phalodi, a taluka town of Jodhpur District. The other site, Kalyan Singh ki Sird is located about 40 km north of Phalodi (Fig. 1). At Bari Bavri, a scatter of potsherds, bones and stone artefacts was noticed on the surface of the 1.5 km wide pebbly sandy channel with insignificant non-cohesive banks (Fig. 2). We systematically collected pottery and other antiquities in an area of about 2 km$^2$ and we took a small (2 x 2 m) test pit to ascertain the stratigraphy of archaeological sediments and the environmental reason for their preservation in an unexpected geomorphic context. The stratigraphy as revealed (from top to bottom) up to a depth of 1.2 m is given in Table 1 and Figure 3.

In the stratified test pit, pottery, charcoal and sediment samples were collected for detailed laboratory studies. Potsherds from the test pit are predominatly red ware. They could not be further identified typologically due to their fragmentary state of preservation. On the other hand, potsherds found on the surface of the gravel are relatively well preserved and some of them show black painting on a red surface. Some of the potsherds appear to have affinities with the Early Historic pottery such as that from Tilwara

**Table 1**: Stratigraphy of the trench at Bari Bavri

| Layer | Depth in cm | Nature of archaeological sediments |
|---|---|---|
| (1) | 0-30 | Pebbly sandy gravel, light pale brown, loose with large number of potsherds, rock fragments, angular blocks of locally derived limestone and sandstone and, well rounded cobbles and pebbles, |
| | | grades to |
| (2) | 30-45 | Light reddish brown sand with admixture of anthropogenic debris, particularly charcoal, ashes, ceramics and bones. At a depth of 40 cm, there is conspicuous evidence of burning in the form of an ash layer of 2-3 cm thickness, |
| | | grades to |
| (3) | 45-65 | Pinkish grey sand with high proportion of anthropogenic materials like ash and charcoal (Fig.4), |
| | | grades to |
| (4) | 65-72 | Light reddish brown sand with very well preserved hearth (20 cm wide, 30 cm deep) rich in charcoal, |
| | | grades to |
| (5) | 72-110 | Relatively compact light reddish brown sand, poor in anthropogenic debris and potsherds. |
| | | sharp contact to |
| (6) | 110-120 | Light reddish brown granular coarse sand of fluvial origin. It is much more compact than layer (5) due to presence of diffused powdery carbonate as a cementing material. |

(Misra 1971). A brick of 37 x 25 x 7 cm dimension was also recovered from the surface and probably belongs to the Early Historic period. Some of the archaeological material at the site therefore might be slightly earlier in age than the dated archaeological component.

Relative dating of the site was done by the fluorine phosphate ratios of bones, which has been standardised by Kshirsagar (1993). The relative dating of bones is based on the principle that the bone buried in the soil absorbs fluorine and the content of fluorine increases with time. Modern bone gives an f/p ratio of 0.03, while fossil bone of Terminal Pleistocene to mid-Holocene may have values between 1-2. The bones of the Late Holocene period (Chalcolithic/Early Historic) usually have a f/p ratio less than 1. The f/p ratio of the bones from Bari Bavri is 0.51, suggesting that site belongs to the Late Holocene period.

**Table 2**: Radiocarbon dates from Bari Bavri

| Depth in cm | Radiocarbon date BP | Lab. No. |
|---|---|---|
| 10-15 | 1490±85 | PRL-2030 |
| 20-30 | 1400±95 | PRL-2031 |
| 70-75 | 1490±95 | PRL-2032 |

Absolute dates of the Bari Bavri were obtained (Table 2) by sending the charcoal collected during the excavation from 10-15 cm, 20-30 cm and 70-75 cm depth to the Radiocarbon Laboratory of the Physical Research Laboratory, Ahmedabad.

These dates concur well with the relative dating of the site as based on f/p ratio (0.51) of bones and typology of pottery. The charcoal collected from layer (4) and (5) is primarily the product of human activity. Secondly, as compared to layer (1), all layers in the trench do not contain pebbles or cobbles. On the whole, the fluvial activity as represented in layer (6) and (5) is moderate and not as strong as in layer (1). Red sandstone bedrock is exposed at a depth of 2 m near the pit. In order to have an additional insight into the nature of archaeological sediments from the test pit, we carried out some preliminary laboratory analysis. The results of chemical analysis are given in Table 3.

As far as the chemical analysis is concerned, phosphorus is the most indicative element for differentiating the anthropogenic sediment from the natural one. It is based on the fact that human activity alters the chemical composition of the deposits. Generally the phosphorus content of a

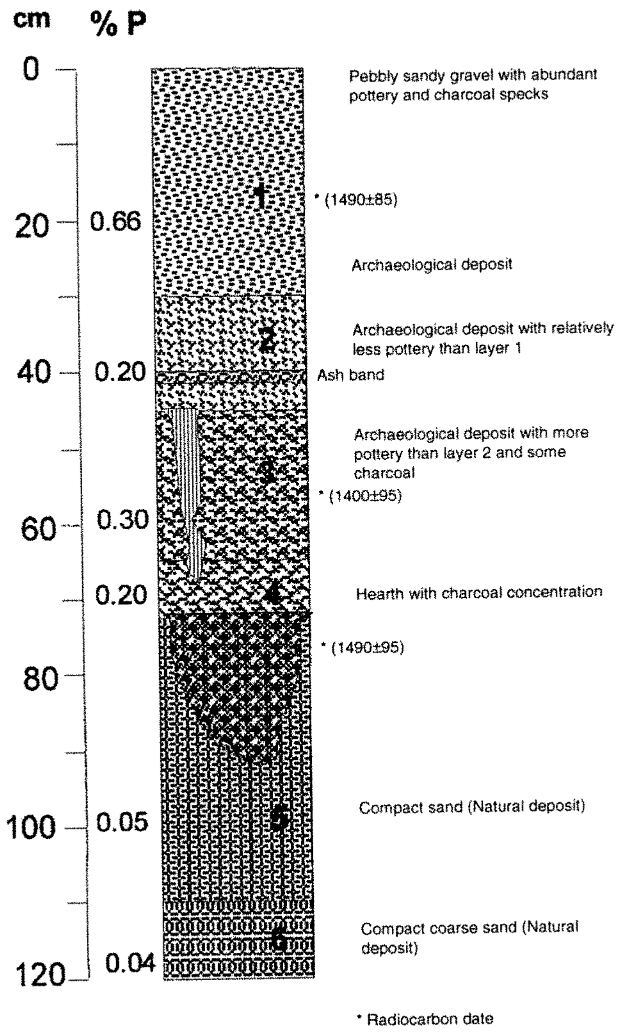
cm
% P
0
20
0.66
40
0.20
60
0.30
0.20
80
100
0.05
120
0.04
1
2
3
4
5
6
Pebbly sandy gravel with abundant pottery and charcoal specks
* (1490±85)
Archaeological deposit
Archaeological deposit with relatively less pottery than layer 1
Ash band
Archaeological deposit with more pottery than layer 2 and some charcoal
* (1400±95)
Hearth with charcoal concentration
* (1490±95)
Compact sand (Natural deposit)
Compact coarse sand (Natural deposit)
* Radiocarbon date

**Fig. 3**: Stratigraphic sequence exposed at Bari Bavri

natural soil and sediment is less than 0.1 per cent. On the other hand, it is greater than 0.1 in sediments affected by human activity. Deotare and Joshi (1981) have established this relationship on almost all major excavated archaeological sites in India.

The representative soil samples from layers (1) to (6) were also subjected to wet sieving to recover palaeobotanical remains of possible food plants. Except for the recovery of broken fruitstones of the Indian jujube (*Zizyphus jujuba* Lamk.) and a few bone fragments, our efforts have not met with much success. This may perhaps speak in favour of the non-agricultural (pastoral) nature of the temporary encampment.

At Bari Bavri, while the total thickness of the deposit is 120 cm, the actual habitational deposit is confined only to a depth of 70 cm as indicated both by 0.20 % phosphate content and the occurance of potsherds. The overall result shows that the maximum intensity of occupation is at the 20 cm level whereas the lowest is at the 100 cm level, as indicated by high (0.66%) and low (0.15%) percentage of phosphate respectively. A slightly higher phosphate value (0.30%) at a depth of 60 cm in layer (3) which yields the maximum unidentifiable red potsherds is a clear indication of an intense habitation for longer duration as compared to the underlying and overlying layers. The intact hearth in layer (4) has not yielded a higher phosphate value probably due to burning activity and due to the short duration of human occupation. The compact layers (5) and (6) are natural deposits on which occupation took place as indicated by very low (0.05 % and 0.04 %) phosphate values. Organic carbon is comparatively high in layer (1) probably due to high occupational refuse and modern channel vegetation cover. Low organic carbon in layers (5) and (6) indicate relatively poor vegetation and no refuse of human origin. Calcium carbonate is in powdery form and diffused in all layers. These layers are therefore, weakly pedogenised.

**Table 3**: Chemical analysis of archaeological sediments at Bari Bavri

| Lab. No. | Layer | Depth (cm) | Colour (as per Munsell Soil Colour Chart) | %P | %$CaCO_3$ | %O.C |
|---|---|---|---|---|---|---|
| 2103 | (1) | 20 | 10YR 6/3 pale brown | 0.66 | 13 | 1.932 |
| 2104 | (2) | 40 | 5YR 6/3 light reddish brown | 0.20 | 15 | 0.536 |
| 2105 | (3) | 60 | 7.5YR 6/2 pinkish gray | 0.30 | 18 | 0.462 |
| 2106 | (4) | 70 | 5YR 6/3 light reddish brown | 0.20 | 14 | 0.158 |
| 2107 | (5) | 100 | 5YR6/4 light reddish brown | 0.05 | 16 | 0.105 |
| 2108 | (6) | 120 | 5YR 6/4 light reddish brown | 0.04 | 14 | 0.063 |

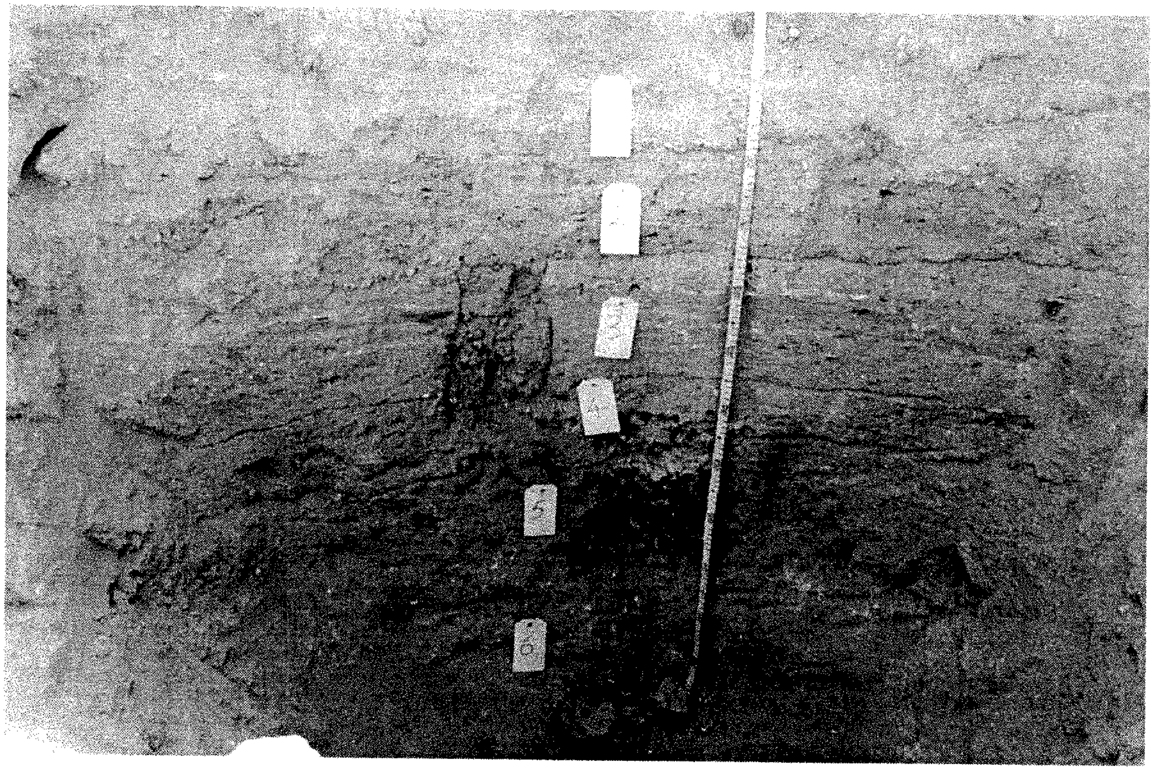

Fig. 4: Well preserved hearth in the archaeological deposit at Bari Bavri

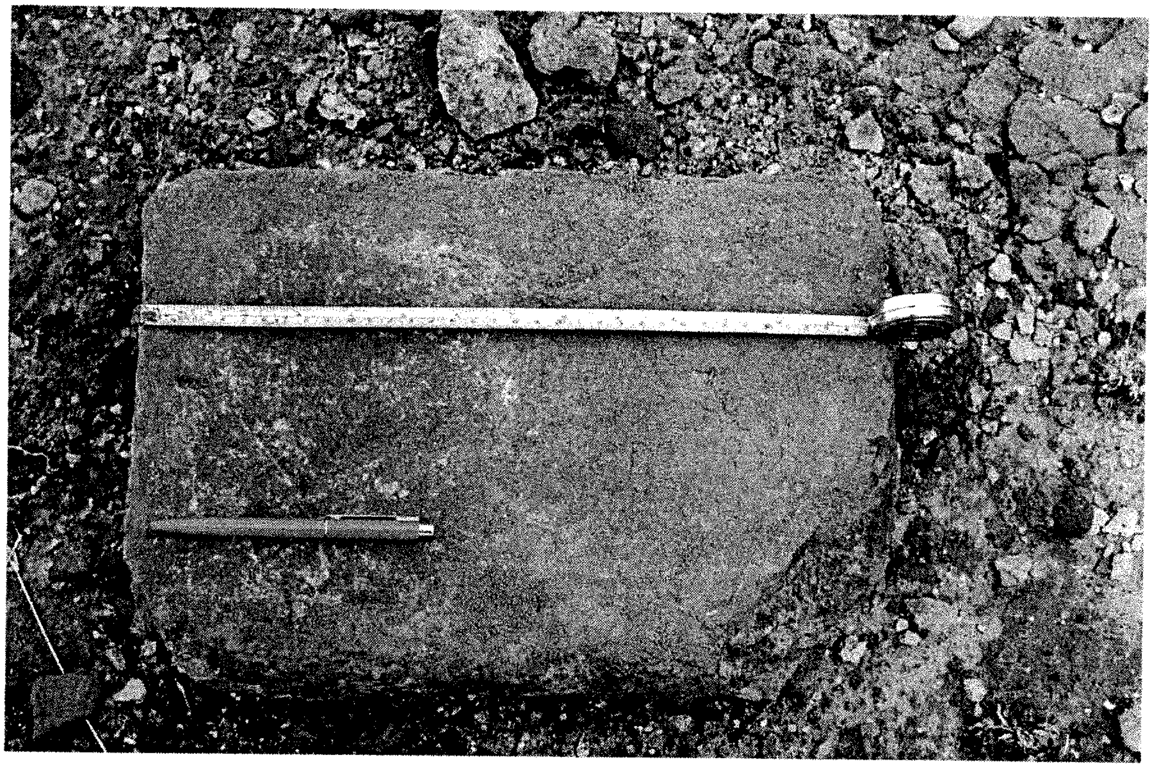

**Fig. 5**: Brick at Bari Bavri

The prominent features of the Bari Bavri site are:

1. about 70 cm thick habitational deposit in the sandy/gravelly channel,
2. the recovery of an intact hearth containing charcoal dated to 1500 b.p. and,
3. the recovery of a well baked brick having 37 x 25 x 7 cm dimension assignable to Early Historic age (Fig. 5).

About 1 km downstream of the archaeological site of Bari Bavri, we found an alluvial fill (2 to 2.5 m thick) on either bank of the stream. The stratigraphy as observed in a number of freshly dug pits in this fill is as mentioned below.

A brownish, non calcareous silty sand occurs up to a depth of 60 cm from the surface. It grades into a weakly cemented pebbly sandy gravel crudely laminated and contains pebbles on sandstone, quartz and cherty limestone (Fig. 6). This gravel rests unconformably on bedrock of cherty limestone. A few semi-rolled Middle Palaeolithic artefacts made on chert were discovered in the pebbly sandy gravel (Fig. 7). On the basis of the absence of microliths and the presence of a few Middle Palaeolithic artefacts, this fill has been tentatively assigned to the Late/Terminal Pleistocene period purely on geomorphological considerations.

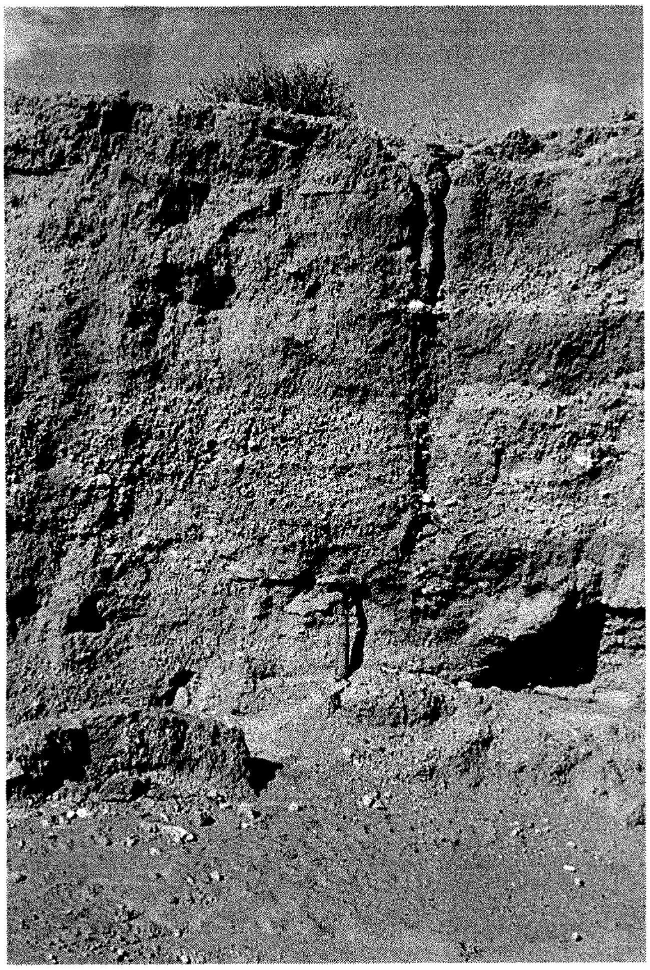

**Fig. 6**: Alluvial fill with artefacts

A little further (about 1 km) downstream of the above mentioned outcrop, we observed a conspicuous alluvial fill (2.5 to 3 m thickness) on either bank of the ephemeral stream flowing over bedrock limestone.

The fill prominently consists of weakly pedogenised brownish sandy silt, crudely laminated. This is interlayered with pebbly sandy lenticular patches of gravels (10-30 cm thick). A good number of moderately abraded potsherds were recovered from this fill. It has been disconformably capped by aeolian sand deposits as an obstruction dune against a limestone hillock (Fig. 8 and 9).

These field observations within a stretch of 3 km in a low sinuosity ephemeral stream has preserved interesting cut and fill features, the significance of which will be discussed later. The Bari Bavri Nala flows for a distance of 6 km further downstream and disappears in low dunes and sandsheets bordering the southern periphery of Bap-Malar playa.

At Kalyan Singh ki Sird, another interesting scatter of potsherds (Fig. 10) and bones similar to Bari Bavri giving 0.71 f/p value of bone was noted. It was seen on the surface of a sheet gravel of 1.5 m thickness resting disconformably on a lithic calcrete developed on a re-worked bouldery cobbly gravel. The potsherds from this site are slightly abraded and the bones are fragmentary making it difficult to assess the material as well as date it correctly.

The occurrence of archaeological material of the historical period in wide ephemeral channels probably indicate temporary/seasonal occupations. Similar types of settlements have recently been discovered by us at Lathi and Mohangarh in Jaisalmer District and their detailed multidisciplinary studies will be carried out in the near future.

## Discussion

Our field observations supported by three radiocarbon dates, and laboratory studies of archaeological sediments of Bari Bavri and typotechnological studies on potsherds bring out the following salient features of the Late Holocene environment in the arid part of the Thar desert.

Feeder streams like the Bari Bavri, are mostly bedrock channels with a high width/depth ratio and non-cohesive banks. They have developed their wide channels over Mesozoic sediments like sandstones, claystones and varieties of limestones. The bedrock lithology has controlled the width/depth ratio to some extent. For example,

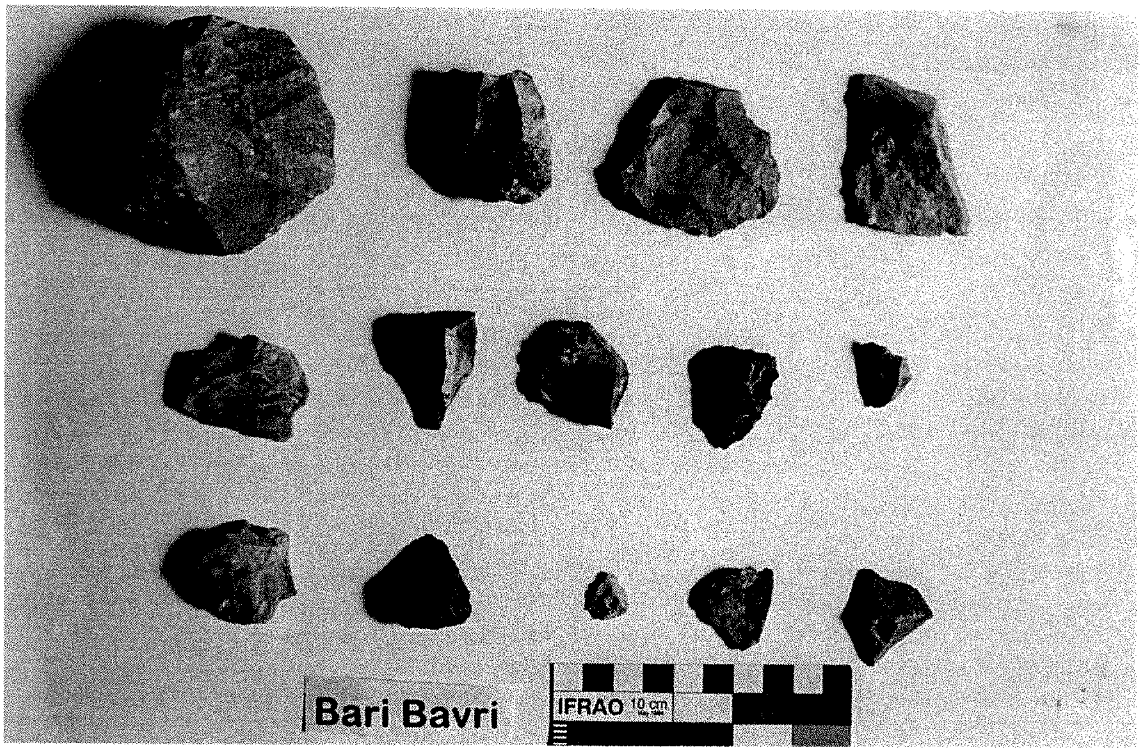

**Fig. 7**: Reworked Middle Palaeolithic artefacts from Bari Bavri

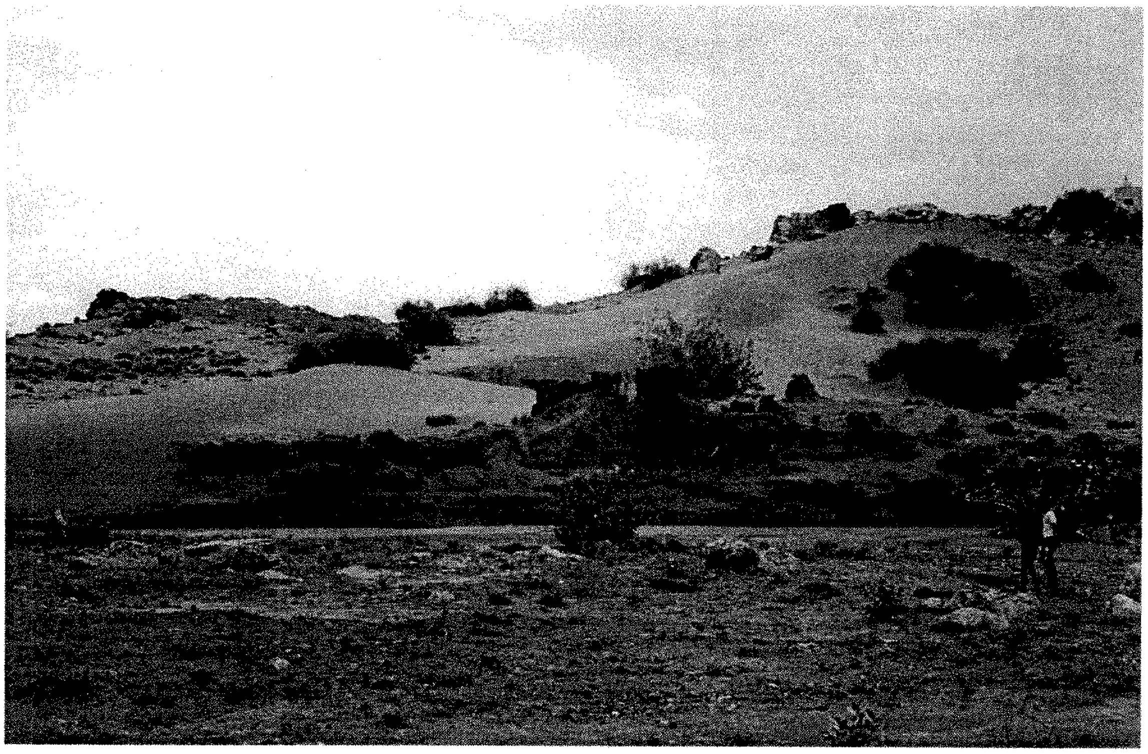

**Fig. 8**: Alluvial fill capped by dune

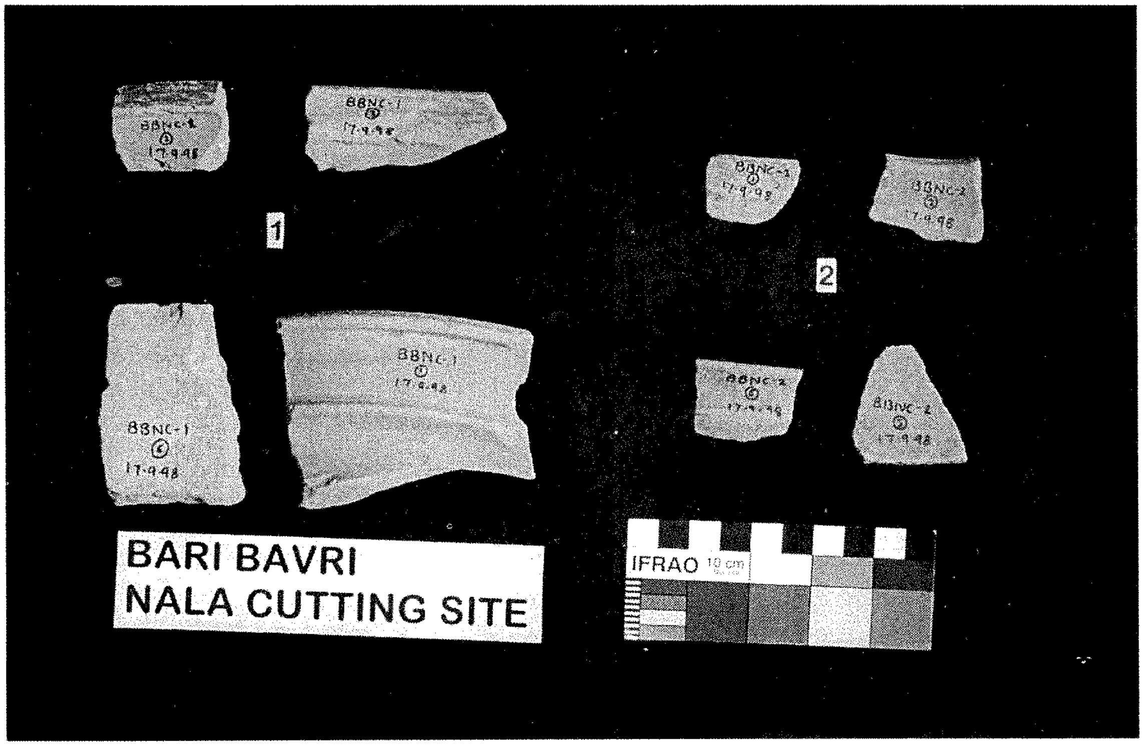

**Fig. 9**: Potsherds from alluvial fill from Bari Bavri site

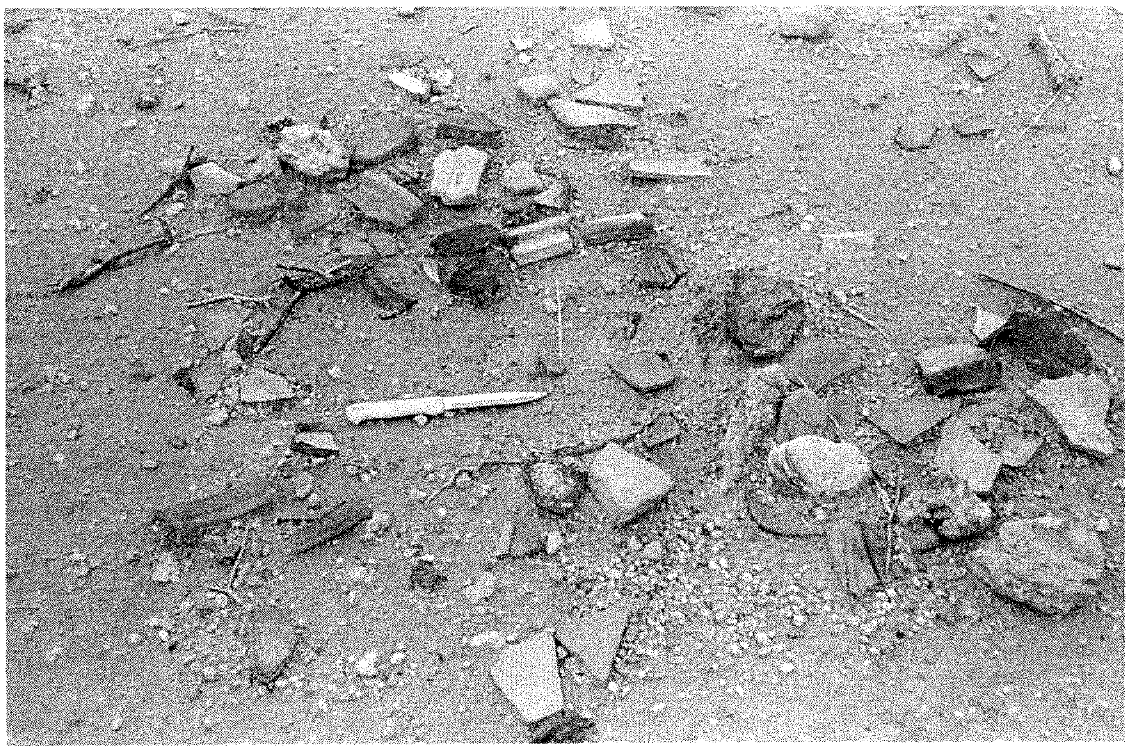

**Fig. 10**: Scattered potsherds on sandy pebbly gravel at Kalyan Singh ki Sird

the Bari Bavri channel is wide (1.5 km) near the archaeological site as it has incised into relatively softer sandstone. On the other hand, the Bari Bavri channel increases its depth due to the presence of relatively hard cherty limestone, occurring 2 km downstream of the archaeological site. The Bari Bavri's wide and shallow channel, has preserved alluvial fills with archaeological materials. Three radiocarbon dates and the archaeological contents of fluvial sediments suggest that the stream has been predominantly aggrading during the Late Pleistocene and Late Holocene (around 1.5 kyr or little later). The same stream has been in an erosional phase during the latest Holocene. It is not easy to interpret the cut and fill activity of an ephemeral stream like Bari Bavri only in terms of climatic changes of the Late Quaternary as a number of variables are involved in stream behaviour in the arid landscape of western Rajasthan where short lived episodic factors like erratic but intense monsoonal rainfall and catastrophic floods play an important role in stream behaviour. Schick (1980) has tried to study the complex problems of the hydrology of ephemeral stream behaviour in the arid (with rainfall <30 mm/annum) parts of southern Negev, Israel. The stream studied by Schick is only 2 km long with a catchment of 0.5 sq km. He observed that 99% of geomorphic activity is accomplished during 5 days by 7 discrete events like high intensity floods. Thus, it may be comparable to the ancient stream activity of Bari Bavri, especially during early historic times.

Inspite of these complex hydrological factors involved in ephemeral stream behaviour in arid regions, we have tried to interpret the available geoarchaeological evidence at Bari Bavri against the available information on palaeoenvironment during the Early Holocene in the Thar desert.

As stated earlier, the Thar desert witnessed strong aeolian activity and sand accumulation between 14 kyr and 11 kyr due to intensification of summer monsoons. The rainfall was relatively intense during the Early Holocene (i.e., between 8-6 kyr) and became weak after 5 kyr. These climatic fluctuations have affected the hydrology of the Bap-Malar playa during the Holocene. Table 4 gives the approximate correlation between climate, playa (Bap-Malar) hydrology and stream (Bari Bavri) behaviour.

Table 4 shows that there is some interrelationship between hydrological changes of the Bap-Malar playa and the behaviour of the feeder stream like Bari Bavri. We require additional data on other feeder streams before we try to generalise on this interesting aspect of the relationship between lake hydrology and its feeder streams having more or less similar rainfall regimes.

The other important aspect of our study is the preservation of an intact hearth, a well baked brick and unabraded potsherds of late Gupta period (~500 A.D.) in the sandy/gravelly channel of the Bari Bavri. It appears that the high width/depth ratio of the channel reduced erosive capacity during high intensity floods. Wells (1980) had conducted a detailed study on the hydrology of ephemeral streams in the alluvial fan context of the arid southwestern part of the USA and has observed that the scouring activity of a stream during flood is insignificant in wide sandy gravelly channels having small catchment areas. The armouring effect of cobbles and pebbles in a sandy gravelly channel has also been observed by Deodhar and Kale (1999) in allocthonous streams in upland western Maharashtra, however without archaeological materials. Similar results have also been observed by Schick (1980) in ephemeral streams in the arid parts of southern Negev, Israel. It is quite likely that a time period between subsequent flood events may be long enough for the preservation of archaeological objects with minimal disturbance. The presence of pebbles and cobbles, derived from the local conglomerate in the area in the uppermost part of the

**Table 4**: Geomorphic environment around Bap-Malar playa

| Event | Approximate Age ($^{14}$C) | Playa Hydrology (Bap-Malar) | Stream Behaviour (Bari Bavri) | Palaeoclimate |
|---|---|---|---|---|
| 1 | Latest Holocene<br>(<1000 bp)<br>(~1500-1000 bp) | Dry, occasional flooding | Down cutting succeeding channel aggradation | Arid |
| 2 | Mid to Early Holocene (~8000-5000 bp) | Ephemeral lake full stage | Down cutting | Semi-arid moderate to strong monsoons |
| 3 | Terminal Pleistocene to Early Holocene (~16,000-8000 bp) | Ephemeral with periodic flooding | Channel aggradation succeeding down cutting | Arid to semi-arid, moderate monsoons. |

archaeological site suggests that high intensity floods did occur towards the terminal phase of site occupation. Even during such a flood the scouring effect may have been minimum due to the tendency of the channel to widen. The uppermost cobbly, pebbly layer (1) protected the archaeological site from further erosion due to the armoring effect of the gravelly channel of the stream.

Thus the preservation of archaeological materials in a wide sandy gravelly channel during the 5th century A.D. in an undisturbed geomorphic context probably indicates that channel aggradation due to intense and short floods took place with a long time interval in between subsequent flooding events.

The alluvial fill about 2 km downstream of the above mentioned archaeological site occurs in a slightly narrow and incised bedrock valley. As shown earlier, this fill contains abraded potsherds derived from the site in the upstream area. This fill is later than the channel aggradation described above. The aggradation took place probably due to blocking of the channel by aeolian sand further downstream towards the Bap-Malar playa. Our geomorphological, geochronological and archaeological studies carried out in the environs of the playa and also near Khara-Bikampur, 30 km NW of Bap show that there are two generations of dune sand/sandsheet activity. The older and higher aeolian sands are stabilised, at times occupied by Mesolithic pastoralists during the Early-Mid Holocene (~7-5 kyr) and the lower younger dunes range in age from 2 kyr and later. The last phase of major dune development occurred around 600 to 700 b.p. in the Thar desert (Kar *et al.* 1998). It is therefore, quite likely that the fill containing late Gupta potsherds might have been formed as a result of blocking of the stream during the major aeolian activity assignable to around 600-700 b.p.

These geoarchaeological studies demonstrate that the preservation of this late Gupta settlement in an ephemeral sandy channel was partly due to hydrological factors as mentioned above and partly due to the long interval between flood events. The latter aspect could possibly be due to increased aridity as a result of global climatic change around 1500-1000 b.p Kale *et al.* (1997) have also observed reduction in flood activity of the river Narmada in the sub-humid part of central India after the 5th century A.D. These two examples of reduced flood activity in the Narmada Valley and at the Bari Bavri in western Rajasthan, in two opposite climatic settings, cannot be used for palaeoclimatic interpretation. These geomorphic features to some extent at least indicate environmental degradation around 1500-1000 b.p., possibly coeval with the "European Dark Age". These changes therefore, appear to be partially responsible for the cultural deterioration in western Rajasthan.

## Acknowledgements

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# Prehistoric Cultures and Late Quaternary Environments in the Luni Basin around Balotra

Sheila Mishra, M. Jain[1], S.K. Tandon[1], A.K. Singhvi[2], P.P. Joglekar, S.C. Bhatt[1], A.A. Kshirsagar, Sonali Naik and Aarti Deshpande-Muhkerjee

Department of Archaeology
Deccan College
Pune 411 006

1 Department of Geology
Delhi University
Delhi 110 001

2 Physical Research Laboratory
Navrangpura
Ahmedabad 380 009

## Abstract

Late Quaternary palaeoenvironments of the Thar desert, have recently been studied as part of a multi-institutional and interdisciplinary project. Detailed geological work has been carried out on the Luni river to understand its response to changing Quaternary climate. In the course of this work a number of prehistoric sites have been dated by luminescence techniques and the palaeoenvironmental framework elucidated. Three phases of prehistoric occupation can be distinguished. An Acheulian handaxe found on the surface of a hill near Bajawa village attests to the presence of man in the region during Lower Palaeolithic times. A gravel, containing flakes, near Karna village has been dated by IRSL (Infrared Simulated Luminescence) to ~80 kyr. A Chalcolithic occupation of a gravel surface at Manawara has been dated by the fine grained TL (Thermoluminescence) method to ~3.4 kyr. This site was covered by a sand dune dated to around 2.9 kyr by GLSL (Green Light Simulated Luminescence) and exposed during the 1979 Luni flood.

## Introduction

Prehistoric studies in the Luni basin were initiated by Misra (Misra 1962), who explored its upper catchments and tributaries. Although many finds were from the present river channel their provenance was identified as a cemented gravel horizon exposed in the river banks. A few of the artefacts were located in situ and some finds from the river channel retained traces of the gravel matrix. This gravel horizon does not occur downstream of Samadri. Middle Palaeolithic elements such as prepared cores and retouched flakes were identified from this assemblage. A total of 15 small, symmetrical handaxes with many flake scars were found from different localities. No dating of any of the sites was possible then and little further prehistoric work was done in the Luni basin. Allchin *et al.*(1976) reported a number of sites elsewhere in the Thar desert and later work by Misra *et al.* (1982) concentrated in the area around Didwana. Some prehistoric sites were also reported by Mishra *et al.* (1993), Mohapatra *et al.* (1963) and most recently by Deotare *et al.*(1998) from other parts of the Thar desert. The predominance of the Middle Palaeolithic sites in the Thar desert has been noted by all the previous workers along with the absence of Upper Palaeolithic sites. Lower Palaeolithic sites are also well known but have mostly been identified from quarries. From the surface only sporadic occurrences of handaxes are known.

Mesolithic/Microlithic/Chalcolithic settlements of the Early and Mid-Holocene are also known from the region. Misra (1970, 1971a, 1971b) explored the region and excavated the site of Tilwara whose fauna was studied by Thomas (1977). The site of Manawara, reported here is close to Tilwara and although the pottery from the two sites is different, the fauna are very similar.

The harsh environment of the Thar desert is a challenge to man's powers of adaptation. During much of the Quaternary, global climates were more arid than at present and it is likely that this environment was occasionally too hostile to support human populations. Consequently an understanding of human adaptations through time and under different climatic regimes has been a major focus of research by archaeologists working in the Thar desert (Allchin *et al.* 1976; Misra 1989; Misra and Rajaguru 1989). Our recent work extends this effort both in respect to prehistoric and palaeoenvironmental studies.

## Quaternary Geological Studies

The Luni, the only river in western Rajasthan, derives its discharge primarily from the source zone, in the foothills of the Aravalli mountains. Around Balotra, the present Luni flows through a landscape dominated by stabilized sand dunes. The local runoff does not reach the Luni, but on the south drains into a depression and on the north into the Pachpadra salt lake. Thus, in this stretch the flow of the Luni is sustained by the rainfall in the source region. The river takes a sharp bend near Tilwara. Between Karna and Sindari villages (Fig. 1), the Luni channel flows through a

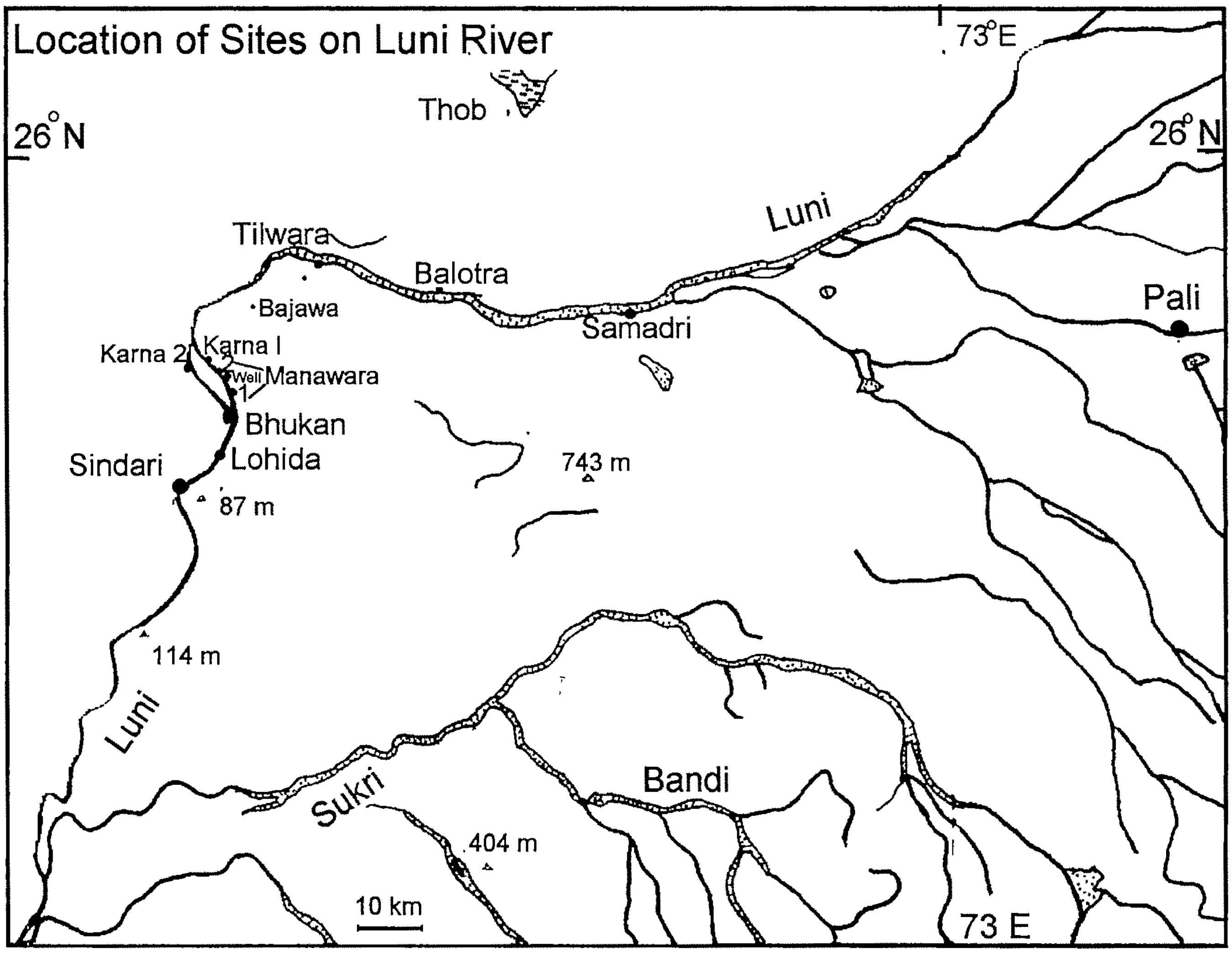

**Fig. 1**: Location map

shallow gorge ~7-14 m deep. Jain *et al.* (1999) have proposed an informal alluvial stratigraphy distinguishing Type I, Type II and Type III sequences. Conspicuous differences in facies and their associations within these sequences were shown to occur in response to changing climates during the Quaternary.

The Type I sequence is older than 400 kyr (Jain *et al.* 1999; Tandon *et al.* 1999) and is possibly a part of a > 300 m buried sequence (Shridhar *et al.* 1994). Similar units are exposed in the Mahi and Sabarmati basins and Tandon *et al.* (1999) have correlated them with the Type I sequence of the Luni basin. No artefacts occur in this unit which may belong to the period before human occupation of the area.

The Type II sequence is exposed near Karna village and at Bhukan I locality (Fig. 1). This sequence includes channel gravels and overbank floodplain facies. Near Karna village, one flake was found in the gravel dated to ~80 kyr (GLSL). No artefacts were found at Bhukan I locality. The exposed surface of the gravel at Bhukan I yielded some additional flakes and an ostrich eggshell fragment, which are most likely derived from the gravel itself. Although the archaeological material is not abundant, or diagnostic of any particular period, the dating of the context is important as very few sites of this age have been dated anywhere in the world.

The Type III sequence begins with a major phase of fluvial activity shown by an extensive palaeo-channel present on the left bank of the Luni river between Karna and Lohida. This gravel, overlying the present Luni gorge, has been dated by IRSL (infrared simulated luminescence) to 11.4 kyr, showing that the gorge exhumation has been later. At Manawara I, the exposed palaeochannel was occupied by humans whose pottery and animal bones were covered by aeolian sand until exposed by the 1979 flood.

The Type I sequence is older than 400 kyr and represents a much more humid climate than that of the present. There is an unknown time gap between it and the Type II sequence. This time gap is at least 300 kyr, as established by the dating attempts but it could be much more. The Type II sequence begins with gravel-floodplain association around 80 kyr (oxygen isotope stage 5a, Tandon *et al.* 1999) which represents a relatively wet period during the Late Pleistocene, followed by dwindling fluvial activity and increasing aeolian dynamism in the study area. The subsequent wet phase is indicated by the Type III sequence that begins with the gravel around 11.4 kyr (IRSL). This suggests an amelioration of the climate at the Holocene-Late Pleistocene transition after the peak of the last glaciation. The Luni re-occupied the gorge shortly afterwards leading to the abandonment and preservation of this Early Holocene channel. Continued relatively humid climate prevented the encroachment of aeolian sand over this unit until around 2.8 kyr (GLSL).

The observations of the localities studied follows in the order of upstream to downstream localities.

## Geoarchaeological Observations

### *Bajawa*

A single handaxe was found near the top of a rhyolite hill to the south of the river (Fig. 1) near Bajawa village. It is made from a rhyolite different from that of the hill. The handaxe has been severely weathered, with a thick weathering rind and pitted surface. It is a symmetrical pointed ovate made on a side flake and measures 12.75 x 7.49 x 2.55 cm. Weathering has obliterated the details of the flaking. An elongated retouched flake with inverse retouch on the right margin and normal retouch on the left margin, measuring 5.7 x 2.62 x 1.17 cm was also found on the same hill. These finds show that man occupied this arid region during the Lower Palaeolithic period. As the human activity is likely to be coeval with more humid climatic episodes this implies an age prior to the last interglacial. This is in view of the fact that an uncorrected uranium series date places the Middle Palaeolithic horizon in the last interglacial at 16 R near Didwana (Raghavan *et al.* 1989). The Acheulian stage should pre-date the Type II sequence.

### *Karna I*

This locality is on the right bank of the western of the two Luni channels upstream of the road between Karna and Dandali villages (Fig. 1). It is one of the major localities where Type II sequence with about 3-4 m of gravel is exposed.

The Karna exposure of Type II sequence has yielded one in situ flake and six flakes and a fragment of ostrich eggshell from the exposed surface of the gravel. The dimensions and descriptions of the flakes are given in Table 1. The flake assemblage is on locally available rhyolite and the flake sizes are quite standardized being between 3-4 cm in maximum dimension. Very little cortex is seen on any of the flakes and this shows that the cores were well exploited. Some striking platforms show the use of indirect percussion or soft hammer technique. Dorsal flake scar patterns are both multidirectional and single or alternating directions. None of the flakes is retouched. This assemblage is not diagnostic of any particular stone flaking technology and although not incompatible with an age of around 80 kyr, it could as well belong to a younger episode of human activity.

**Table 1**: Dimensions and description of flakes from Karna I

| L (cm) | W (cm) | Th (cm) | Description |
|---|---|---|---|
| 4.5 | 4.19 | 1.26 | Core fragment. Cherty rhyolite, slight abrasion, six flake scars on one surface and two on other surface, platform missing. |
| 2.32 | 4.44 | 1.04 | Flake fragment of brown rhyolite |
| 3.59 | 4.34 | 1.00 | Brown rhyolite flake |
| 2.6 | 4.45 | 1.19 | Purple rhyolite, flake terminates in snap fracture |
| 2.79 | 2.15 | 0.59 | Flake of purple rhyolite |
| 4.7 | 2.9 | 1.2 | Flake of purple rhyolite |
| 4.0 | 3.92 | 1.15 | Flake of purple rhyolite, in situ |

### *Karna II*

Another small collection of flakes was made from the left bank of the easterly channel of the Luni on the downstream side of the Karna-Dandali road. The dimensions and descriptions of these flakes are given in Table 2. The gravel here has similar characters to that of Karna I and is cemented. These cemented horizons are being used for building material and so recently dug out gravel was available for searching for artefacts. A number of flakes were found in situ in the dug out blocks of gravel. The characters of this gravel are similar to those of the Karna I locality.

**Table 2**: Dimensions and description of flakes from Karna II

| L (cm) | W (cm) | Th (cm) | Description |
|---|---|---|---|
| 5.38 | 3.84 | 2.11 | Pinkish rhyolite, surface pitted and slightly abraded, unidirectional flake scars |
| 5.3 | 4.59 | 1.05 | Banded purple rhyolite, multidirectional flake scars |
| 4.3 | 2.69 | 0.97 | Purple rhyolite |
| 3.54 | 3.47 | 1.15 | Quartzite flake fragment |
| 3.4 | 1.82 | 0.65 | Black chert blade |

*Manawara II*

This locality was selected as a small gully has exposed a 3 m fluvial sequence. This was scraped and the detailed measurements and dating of this section made (Fig. 2 ). The locality is important because of a well dated stratigraphy for the Early Holocene fluvial sequence. The fluvial sequence consists of sandy gravels and sands. The gravels have pebbles of a maximum size of 3-4 cm and modes in the coarse sand to fine gravel size. Angular rhyolite and sub-angular calcrete nodules dominate the pebble clast composition. The sand units were selected for dating. A sand unit overlying a gravel has been dated to ~9.8 ± 0.7 kyr (Table 8). The lower gravel in this sequence therefore is probably close in time to the gravel from Manawara I which is dated to ~11.4 kyr. The aeolian unit overlying the fluvial sequence is dated to ~2.8 kyr at Manawara II. At Manawara I the gravel was overlain by an aeolian unit that may be belong to the same time as it covers pottery dated to ~3.4 kyr.

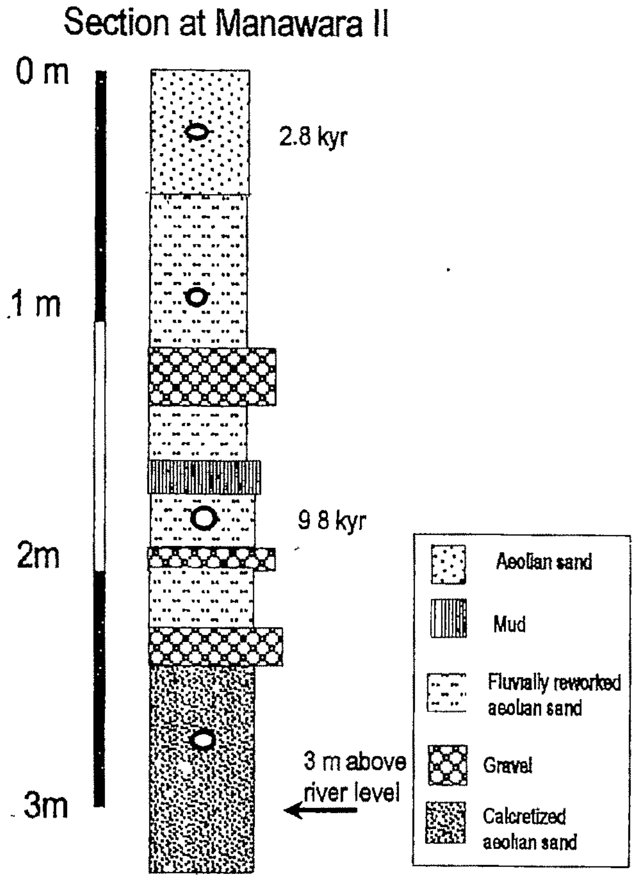

**Fig. 2**: Manawara II section of sites in the Luni valley

*Manawara well*: This locality is an extension of the Manawara gravel. The scoured surface of this gravel was searched and a number of flakes, four potsherds and three ostrich eggshell fragments collected. The dimensions and description of the flakes are given in Table 3.

**Table 3**: Dimensions and description of flakes from Manawara Well locality

| L (cm) | W (cm) | Th (cm) | Description |
|---|---|---|---|
| 4.32 | 3.99 | 1.26 | Purple rhyolite, cortex on right margin, slightly abraded, hard hammer blow |
| 4.00 | 3.64 | 0.95 | Grey brown rhyolite |
| 2.14 | 2.88 | 0.88 | Quartzite, abraded, wide angle platform |
| 2.29 | 3.94 | 1.92 | Purple rhyolite, unabraded, a fragment of a bifacially prepared piece |
| 2.70 | 2.62 | 0.47 | Grey green rhyolite, hard hammer |
| 2.35 | 1.18 | 0.47 | Blade fragment |
| 3.21 | 3.25 | 0.95 | Purple rhyolite, triangular flake, hard hammer |

*Manawara I*

The Manawara I site is a gravel spread near the present Manawara village. The gravel is more than a metre thick with thick trough cross beds. Local inhabitants report the stripping of the aeolian cover during the flood of 1979. Bones, pottery and other archaeological material were found on the surface of the gravel. The pottery and bones have a coating of calcrete and are mostly unabraded. The bones have a fluorine/phosphate ratio between 1 and 1.5 (Table 5). The condition of the artefacts and bones led us to conclude that they were buried until recently. The fluorine/phosphate ratios imply that the assemblage dates to the

Early to Mid-Holocene period. Radiocarbon dating of gastropods from this gravel and a second locality at Lohida (Table 7) gave dates close to around 7.5 kyr. No pottery is known for such an early period in India. Independent dating of the gravel and pottery by GLSL and TL therefore was important in resolving the issue (Fig. 9). The pottery TL dates to ~3.4 kyr and the gravel GLSL dates to ~11.4 kyr. The archaeological material represents a temporary occupation of the gravel surface and was preserved by its burial by aeolian sand shortly after the occupation. The aeolian cover is dated at the nearby locality to ~2.8 kyr. Details of the archaeological material are given as follows.

### Pottery

The pottery from this site is thick (about 1 cm) well fired and with a red slip. The inner portion of many sherds is unslipped and shows the scraping or wiping marks common on Chalcolithic pottery. The slipped surface on most of the sherds is burnished. Two sherds have traces of black painting (lines) on them. Two sherds have wavy appliqué on the neck portion. One has short vertical incisions on the rim. Rims show a variety of forms, gently out turning or with straight collared portions, both of which fit the four fingers of the hand for picking them up. One flared and one featureless rim are also present. One rim is straight with an indentation of one finger width just below the rim. Most of the potsherds collected belong to large jars or basins. A few sherds of grey ware are also present. The pottery is unabraded but has a thick coating of calcrete (almost 1 mm).

For comparison pottery was collected from the surface of the site of Tilwara and studied. The Tilwara pottery is thinner, with a wash rather than a slip and unburnished. Most of the sherds have fibre temper and finger marks from wheel throwing. Both red and grey wares are present. Two sherds of black ware have a 1 cm wide band with decorations made by impressing the clay when wet. One is with nail impressions and the other of cord. The two pottery assemblages therefore are quite distinct. The surface collection at Tilwara therefore may be dominated by material from the Early Historic period. In the excavation both Chalcolithic and Early Historic phases are documented.

### Shell objects

Two shell bangle fragments were found. The manufacture of shell bangles was common during the Harappan period. The presence of shell bangles at this site shows its integration into a larger society, inspite of the ephemeral nature of the site occupation.

### Stone tools

A number of rhyolite flakes were collected from this site. In addition one blade, one small quartz microblade core and a half of a round sandstone grinding stone were found. Descriptions and measurements are given in Table 4. In comparison the stone tools from Tilwara included two cylindrical microblade cores that are long and made of fine-grained rhyolite, in contrast to the short quartz microblade core from Manawara. The stone flaking debitage from Tilwara, however, includes many simple flakes that are similar to those collected from the Karna and Manawara gravels.

**Table 4**: Dimensions and description of stone tools from Manawara I

| L (cm) | W (cm) | Th (cm) | Description |
|---|---|---|---|
| 4.34 | 4.79 | 0.82 | Purple rhyolite flake |
| 3.26 | 4.94 | 0.40 | Grey rhyolite flake |
| 3.95 | 3.73 | 1.23 | Grey green rhyolite flake |
| 1.77 | 2.0 | 2.1 | Quartz microblade core |
|  | 6.7 | 3.09 | Quartzite rubbing stone |
| 2.57 | 1.29 | 0.23 | Pink chert blade fragment |

### Bones

A number of bones were identified from the gravel. The bone identification, description and fluorine/phosphate ratios are given in Table 5. The faunal assemblage is dominated by domestic species, especially cattle. Sheep/goat and buffalo are also present. Wild fauna are not significant. The faunal assemblage is comparable to that of Tilwara (Thomas 1977). The presence of *Equus* sp. is interesting. The measurements of the equid pelvis bone are compared to that of modern ass and horse, but cannot be definitely assigned to either (Table 6). However, given the domination of the assemblage by domestic species, it is probable that the equid is a domestic equid, either horse or ass, important in increasing the mobility of the pastoral community.

### Fluorine/Phosphate dating of the bones

Fluorine from groundwater accumulates in buried bones by the conversion of hydroxyapatite into fluorapatite which is chemically more stable. As this is a chemical process it depends not only on time but also on the amount of fluorine in the environment, as well as temperature and moisture conditions. In using fluorine for dating, the fluorine/phosphate ratio, expressed as $100F/P_2O_5$, is taken, as phosphorus is an integral part of bone apatite. This ratio is independent of the density of the bone. A large number of ancient bones from India have been measured for the F/P ratio (Kshirsagar, 1993). The F/P ratio of the bones from Manawara varies from 1.4 to 0.3. Most of the bones

**Table 5**: Identification, description and fluorine phosphate ratios of bones from Manawara

| Lab no. | Identification | Description | Taphonomy/ Human activity | $100F/P_2O_5$ |
|---|---|---|---|---|
| 626 | *Gazella bennetti* | almost complete horncore of gazelle, right side, Oro-orbital length: 30.85 | | 0.34 |
| 627 | Bos indicus | rib fragment of cattle | cut marks | 1.06 |
| 628 | Bubalius bubalis | Complete astragalus of buffalo lateral length: 64.86<br>medial length: 58.83<br>max. distal width: 40.50<br>max. lateral thickness· 33.52<br>max medial thickness: 33.62 | holes by roots and insects | 1.06 |
| 629 | *Bos indicus* | Complete cattle patella of right side length: 58.85 | charred, abraded | 1.14 |
| 630 | *Bos indicus* | Proximal fragment of right radius-cattle | cut marks | 1.05 |
| 631 | *Bos indicus* | Fragment of cattle tibia | cut marks | 0.8 |
| 632 | *Capra hircus* | Mandible of goat-horizontal ramus of age more than 1 year | | 1.42 |
| 633 | *Bubalis bubalis* | first phalanx of buffalo | chewing by carnivore | 0.95 |
| 634 | *Bos indicus* | Complete caudal vertebra of cattle | abraded | 1.24 |
| 635 | *Bos indicus* | Maxillary molar fragment of cattle | | |
| 636 | *Equus sp.* | Acetabulum of equid length of acetabulum (LA): 57.49 | | 1.42 |

Bone measurements are in mm

**Table 6**: Comparative measurements of equid pelvis

| Specimen | Length of the acetabulum (LA) in mm |
|---|---|
| Manawara I *Equus* sp. pelvis | 57.49 |
| Horse (*Equus caballus*) male USNM 238111 | 59.80* |
| Wild Ass (*Equus hemionus*) female USNM 541427 | 49.40* |

*after Zeder (1986)

have values of around 1. The small variation in the values suggests that all the bones belong to a single assemblage. The lower value of the *Gazella* could be due to the material being horn rather than bone. The non-cattle domestic species (goat and equid) are slightly higher than the cattle which all have almost the same value. F/P ratios for bones from Chalcolithic sites in Maharashtra give values of less than 0.5. Little systematic variation is seen between the various Chalcolithic phases. On the other hand these values compare well with those from a number of sites reported by Deotare *et al.* (1998) in Rajasthan.

### Molluscs

The mollusc assemblage collected from the gravel at Manawara comprises three species of freshwater gastropods belonging to the families of Planorbidae (*Indoplanorbis exustus*), Viviparidae (*Viviparus bengalensis*) and Thiaridae (*Thiara sp.*); and one terrestrial gastropod (*Zootecus insularis*). No bivalves are present in the assemblage. The overall shell assemblage shows good preservation and consists of shells ranging from adult to juvenile specimens for all the species. Shells occur in the size range of 1 cm to 0.5 cm. The *Viviparus* shells are represented by juvenile specimens while the *Zootecus* are mostly adult individuals.

The mixed shell assemblage with shells ranging from adult to very young individuals represents a once living community of all the four species coexisting in the gravel deposit. The freshwater gastropods identified can survive short dry periods since they can resort to aerial respiration as can the land snail *Zootecus insularis* that is also present (Subba Rao 1996). The gastropod assemblage therefore indicates, not flowing water, but localised seasonal accumulation of water which could also explain the absence of freshwater bivalves in the gravel which require adequate water for their growth. The gastropods do not have any economic use and are unrelated to the human activity at the site.

### *Lohida*

The Lohida locality is between the Lohida bus stand on the Balotra-Sindari road and the Luni river. A gravel patch overlies the Type I sequence and is not overlain by anything. The gravel is above the gorge and its relationship to the gorge is such that it would appear that the gorge must have either been filled or was not in existence when the gravel was deposited. Gastropods were common in this gravel as at Manawara II, and were dated. A few abraded potsherds were collected from the Lohida gravel. No Chalcolithic pottery or bones were present.

## Discussion

### *Archaeology*

Three archaeological assemblages can be distinguished from the material collected from the above mentioned localities. The first is the solitary handaxe found on the hill surface, belonging to the Lower Palaeolithic cultural phase. This find is similar to those reported earlier by Misra in the Luni basin and Deotare *et al.* (1998) near the Bap-Malar Rann. The severe weathering of the handaxe precludes a very detailed description but also attests to a significant age for the specimen. The refinement seen in the manufacture of this handaxe indicates that it belongs to the Late Acheulian cultural phase.

The second archaeological entity consists of fresh, unabraded flakes collected from and on gravels at Karna I and II, Manawara Well, Manawara I and II. This group numbers only a few dozen. None of the flakes show any diagnostic features of the Middle Palaeolithic. There are no prepared cores or retouched flakes. However, the context of the flakes has been dated to different times. The Karna I gravel dates to 80 kyr, Karna II is undated, but may belong to the same lithounit. The Manawara localities on the other hand belong to an exposure of gravel dated to ~11.4 kyr by luminescence dating. The similarity of the artefacts in the gravels of different ages could be due to the lack of diagnostic material in the small artefact sample or the recycling of older flakes in the younger gravel. This gravel was exposed until ~2.8 kyr and archaeological material accumulated on the gravel surface. Some of the flakes could even belong to the Chalcolithic as flakes produced in preparing microblade cores from Tilwara also share many characters with these other flake assemblages.

The third archaeological unit is the Chalcolithic material from the surface of the palaeochannel. This consists of the habitational debris of a short term occupation of the locality, preserved by burial under an aeolian cover.

### *Dating the sequence*

An important aspect of the work reported here is the multidisciplinary approach utilized to date the gravel exposed at Lohida and Manawara. Understanding the age of a geological unit is a complex process, where "absolute" dating techniques along with the lithostratigraphy and associated archaeological/biological materials are evaluated. In this study we utilized the associated archaeological materials, the F/P ratios of bones, the lithologies and stratigraphic relationships along with two different absolute dating techniques to determine the age of the gravel unit. Our studies showed that the situation was more complex that initially anticipated but this complexity has added interesting new information.

The gravel exposed at Lohida, and the three Manawara localities has similar sedimentological characters in all the locations. It is either not covered by any other unit or covered with a young aeolian unit. These lithological and sedimentological characters indicate that this gravel at the different localities is likely to be similar in age and young in the sequence.

From the Manawara I locality quite a large amount of pottery and faunal material was collected from the surface. The archaeological material was unabraded but had a coating of calcrete, which implied recent exposure from a buried context. Gastropods were also abundant from the Lohida and Manwara I localities. The abundance and condition of the archaeological material implied that it belonged human activity at the spot and were not stray occurrences washed into the gravel. The pottery and bones were mostly unabraded. The ratio of bones to pottery is high, as expected from a habitational site. The pottery has affinities to the Chalcolilthic pottery of the region, which implies an age of 3.0-4.5 kyr. The bones from the locality also showed a fairly high F/P ratio, although still within the values expected for Holocene samples.

Radiocarbon dating of the gastropods (which are not related to the human activity), was carried out by BSIP, Lucknow. The radiocarbon dates from the two localities are close to each other, which strongly supports the idea that the gravels exposed at the different localities belong to the same channel system. Radiocarbon dates differ from "absolute" dates as the amount of carbon in the atmosphere has not been constant A calibration is available and this allows us to compare the radiocarbon dates with other absolute dating methods. The dates obtained from the two gravels imply an age of approximately 7-7.5 kyr. for the gravel. Remarkable reproducibility of ages from two different localities namely Lohida and Manawara indicates that the contamination if any is negligible.

Luminescence dating techniques were applied to determine the depositional age of the sediments and also the time of firing of the pottery. Luminescence dating has two variants thermally stimulated luminescence (TL) and optically stimulated luminescence (OSL). OSL in turn is of two types — infrared stimulated luminescence (IRSL) and green light stimulated luminescence (GLSL). The terms indicate the stimulation method used in exciting the luminescence from the mineral. While GLSL is usually done on quartz separates, IRSL is done on the K-feldspar grains separated from the sediments after appropriate chemical treatment of the samples. Luminescence methods rely on the thermal zeroing of the pre-existing luminescence (geological luminescence) signal of the minerals during the firing of the pottery or on photobleaching of geological luminescence during the pre-depositonal transport of the minerals to a small residual value. Thus, at the time of burial the minerals have a very low or zero luminescence concentration. On burial further daylight exposure ceases and afresh accumulation of luminescence occurs due to irradiation by ambient radioactivity *viz.* $U^{238}$, $Th^{232}$ and $K^{40}$ and cosmic rays. The total luminescence acquired after burial is directly proportional to the elapsed time since burial. Thus the age of the sample is total luminescence acquired (equivalent dose) divided by the rate at which the luminescence is acquired (dose rate). The advantage of these methods is that the event (such as burial or baking of pottery) is dated directly instead of dating the contextual material as in radiocarbon dating. Also it allows the dating of conventionally undatable material and hence is especially important in the dating of sequences in the arid/semi-arid regions (Singhvi and Krbetschek 1996).

A basic assumption in the method is that the luminescence signal (with respect to the stimulating wavelength) was zeroed (bleached) or near zeroed before burial. Although, this assumption is quite valid in case of TL of baked material such as pottery, etc. and OSL of aeolian sands which are exposed to a long duration of sunlight before coming to rest, there can be some uncertainty regarding the complete bleaching of fluvially transported material. Inadequate bleaching, if any, in such cases can lead to overestimation of ages. Jain *et al.* (1999), however, carried out a feasibility study on alluvial sediments of the Thar and concluded that they are amenable to OSL dating. Also the sand from one metre depth beneath the present Luni channel gave an age of ~75 years indicating that the fluvial sands were well bleached. The gravel at Manawara

**Table 7**: Radiocarbon dates from Manawara and Lohida

| Lab No. | Sample ID | Site | Date | Calibrated Date* | 1σ standard Deviation |
|---|---|---|---|---|---|
| BS 1412 | MNR-1 | Manawara | 6520±150 | 7390 | 7530-7490, 7480-7230 |
| BS 1419 | LHD-1 | Lohida | 6900±120 | 7670 | 7870-7870, 7800-7570 |

*Calibration is using Calib 3 program of Stuiver and Pearson (1993). Due to "wiggles" in the curve one $^{14}C$ age intercepts the curve twice for both the dates.

**Table 8**: Luminescence dates from Manawara and Karna

| **Sample no.** | **Locality** | **Luminescence Method** | **U (ppm)** | **Th (ppm)** | **K(%)±5%** | **Dose Rate (Gy/ka)** | **ED(Gy)** | **a (kyr)** | **Age** |
|---|---|---|---|---|---|---|---|---|---|
| Tr158 | Karna | GLSL | 1.69±0.32 | 3.95±1.13 | 1.5 | 2.09±0.12 | 166±15 | – | 80±9 |
| Sh0 | MnII | GLSL | 2.5±0.48 | 5.73±1.63 | 1.4 | 2.28±0.16 | 6.5±1 | – | 2.9±.5 |
| Sh3 | MnII | GLSL | 2.32±0.60 | 9.97±2.06 | 1.71 | 2.80±0 .20 | 27±1 | – | 9.8±.7 |
| Pt1 | MnI | TL | 3.41±0.95 | 12.64±3.28 | 1.5 | 14.48±1.24 | – | 0.06 | 3.4±.3 |
| Tr154 | MnII | IRSL | 1.9±0.5 | 6.8±1.8 | 1.7 | 3.3±0.2 | 37.3±2.67 | – | 11.4±1.2 |

I and sand from Manawara II were dated by GLSL. Similarly there could be a problem of underestimation in the radiocarbon ages on account of contamination by younger shell material. However the correspondence in the ages of shell collected from two different locations give a confidence in this age. The gravel and gastropod shells are therefore not syndepositional but represent two different events. The gastropod assemblage might belong to a time later than the gravel deposition, with the gravel providing a favourable environment for gastropods even after the main Luni channel has already shifted to a different location. This is possible given the ecology of the species discussed above.

The Type II gravel, at Karna I locality gave an age of 80 kyr. This date is important in that it shows the presence of a Luni channel in the Late Quaternary. Archaeological material associated with this gravel is meagre and undiagnostic, but shows the human adaptation to an arid environment at that time. Further work is needed to find more archaeological material in the Type II gravels.

### Palaeoenvironment

Two phases of Luni gravel deposition have been identified, dating to around 80 kyr and 11.4 kyr. It would appear that these were periods when the fluvial system was more dynamic in Western Rajasthan. The dating of multiple "events" at the Manawara Lohida gravel gives us a record of the changing environmental conditions at that particular spot in the landscape. These are, the increased fluvial activity at ~11.4 kyr with the Luni re-excavating the gorge between Karna and Lohida shortly afterwards. The continued humid climate ensured that the gravel provided a congenial environment for gastropods for some time (perhaps up to 5 kyr) after which the channel was abandoned. The dates close to ~7.5 kyr from the two sites may either represent a composite age over an extended period of time or colonization for a short duration. We believe that the gastropods are unlikely to be younger than around ~5.6-5.9 kyr, which marks the beginning of a relatively arid phase in the Thar (Enzel *et al.* 1999). Maximum lake

**Table 9**: Summary of palaeoenvironmental inferences of the Luni

| **Lithounit** | **Age** | **Palaeoenvironmental Inference** |
|---|---|---|
| Type I sequence | >400 kyr | Presence of re-worked clasts and calcrete indicate a semi-arid climate, but much more humid than that of today |
| Type II sequence | 80 kyr | Correlated to the humid phase of OIS 5a. Increasing aridity seen in the sequence |
| Type III sequence | 11.4 kyr | Re-establishment of fluvial system after the peak of Late Pleistocene aridity |
| Type III sequence | 11-5 kyr | Luni floodplain development after the re-occupation of the gorge. The former Luni channel provides a habit for gastropods which date to 7.5 kyr |
| Chalcolithic | 3 4 kyr | Occupation of the gravel, by Chalcolithic agro-pastoralists showing the continuing absence of aeolian cover |
| Aeolian cover | 2.8 kyr | The Early Holocene Luni channel was covered by aeolian sand indicating an increase in aridity during this time. This has preserved the evidence for the Chalcolithic occupation of the gravel |
| Erosion of aeolian cover | 1979 | The aeolian cover was washed away from the Manawara I locality during the 1979 flood. This is one indication that the 1979 flood was one of largest on record, perhaps unprecedented since the Early Holocene |

levels in the region, reported from the Lunkaransar, occurred around 7.1 kyr (Enzel *et al.* 1999). It is possible that the peak of the gastropod community corresponded with the maximum lake levels in the Thar and the community was decimated with the beginning of the arid phase. This is also borne out by close correspondence in the ages of the molluscan shells with the highest lake levels. Interestingly the age of the last fluvial unit of the Manawara II section also gives an OSL date of ~5 kyr indicating that there was a simultaneous dwindling of the fluvial regime along with the falling lake levels. This obviously must effect the proximal lakes/ponded water situation such as at Manawara I and lead to decimation of the molluscan community.

The gravel surface was free of aeolian cover until 3.4 kyr when humans occupied it. Sometime between 3.4 kyr and 2.8 kyr the aeolian cover advanced over the gravel in the Manawara locality. Additional evidence of increased aeolian activity at this time are given by Kar *et al.* (1998) and Thomas *et al.* (1999). This cover was only exhumed recently, which indicates that the recent floods are probably among the largest in the Late Holocene.

## Conclusions

The archaeological and palaeoenvironmental record from the Luni river near Balotra adds some new information to our understanding of prehistoric adaptations to the changing Quaternary environments. A close correspondence is witnessed between climate, fluvial regime and habitation. Two chronologically constrained phases of Luni gravel deposition have been identified around 80 kyr and 11.4 kyr. It appears that these were periods when the fluvial system was more dynamic in western Rajasthan.

The Lower Palaeolithic phase is not chronologically constrained but we suggest that it is bracketed by the Type I and Type II sequences of Jain *et al.* (1999), possibly during a wet phase. Although, the artefacts derived from the gravels of the Type II sequence are undiagnostic, they may belong to the Middle Palaeolithic as also indicated by the age of the context. Similar artefacts are also found from the younger gravels (~11 kyr) which may be due to recycling of the material or the non-diagnostic nature of the artefacts. In the field, archaeological material and gastropods from the gravel were associated with this gravel but a multidisciplinary dating programme showed that the gravel, gastropods and human activity did not belong to the same time. The interdisciplinary approach of geoarchaeology has provided us with a deeper understanding not only from the point of view of the archaeological but also the palaeoenvironmental evolution in the region. Further work in both aspects is likely to be more rewarding.

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# Evolution of Parabolic Dunes: a Case History from the Eastern Fringes of the Thar Desert, Rajasthan, India

K.S. Raghav and A.K. Sinha[1]

228, Shreejee Nagar
Durgapura, Tonk Road
Jaipur 302 015

[1] Department of Geology
University of Rajasthan
Jaipur 302 004

## Abstract

Parabolic dunes are associated with barchan, linear and transverse dunes. They occur in varied physiographic settings with different conditions of sand supply, wind regime and rainfall. They belong to different aeolian episodes ranging from older fixed parabolic to active parabolic dunes. Grain size and moisture content of the soil are locally significant in the stabilisation of the dunes. The substratum, topography, availability of sand and prevailing wind speed and direction also play an important role in the formation of parabolic dunes.

## Introduction

Various types of landforms are found in the Thar desert. The southwestern and northwestern parts are bounded by deltaic and floodplain deposits of the Indus, a perennial river system. The southern part is covered by the Rann of Kachchh whereas the southeastern part is bounded by the ephemeral Luni River and its tributaries originating from the NNE-SSW trending Aravalli hills. The northeastern part of the Aravalli hills are covered by the Jaipur upland. This area is drained by several inland ephemeral rivers like the Kantli, Mendha, Rupangarh, Banganga, Sabi and Sota. The river Bandi joins the Yamuna, a perennial river system lying to the north (Fig. 1).

The central part of the Thar is covered by various types of dune fields which are separated at places by rocky pediplains. The climate of the study area varies from arid to semiarid. The pattern of isohytes reveals four main rainfall belts: (i) 500 to 800 mm: eastern fringe area of the Thar desert lying east of the Aravalli hill range, (ii) 300 to 500 mm: west of the Aravalli hill range, (iii) 100 to 300 mm: east of zone ii, and (iv) less than 100 mm: in the extreme west. The trend of isohytes is from NE-SW and rainfall gradually decreases from SE to NW. The maximum summer temperature (May-June) in most parts of the area normally varies from 40.50° to 42° C although in some years it can reach 48° to 50° C at places (Krishnan 1977). The temperature and wind speed also peak in May and June. The strong prevailing winds during the months of June to July are almost unidirectional from the southwest over the Thar desert, especially in the Jaisalmer area. In September the wind direction begins to change and during November the northeast monsoon is established. The winter season extends from December to February. During January, the maximum temperature is 20° C. The average wind speed during June is more than 25 km/hr in the western part, while it is 10 to 15 km/hr in the eastern part. The highest drift potential at most stations in the Thar desert occurs in June causing desert storms in the area (Middleton 1989).

Several hypotheses have been put forward to explain the morphological features of the parabolic dunes (Copper 1967; Landsberg 1956; Hogbom 1973; Hack 1941; Hafley and Sidwell 1945; Melton 1940; Verstappen 1970-72; Mckee 1966-79; Price 1950; Pye 1982a, 1982b, 1983; Anton and Vincent 1986; David 1981; Raup and Argus 1982; Shulmeister and Less 1992; Bigarella 1975; Eriksson *et al.* 1989; Goudie and Thomas 1986; Wasson and Hyde 1983; Wasson *et al.* 1983). They have suggested that sand availability, wind regime and vegetation cover are the most important factors whereas grain size sorting and moisture content are locally significant in the development of parabolic dunes.

The present study brings out the overall influence of the underlying topography, i.e. landforms, their dimensions and their relationship with the wind regime and sand availability, as being one of the most important factors in the evolution of parabolic dunes.

Extensive fieldwork and studies of satellite imagery on 1:1,000,000 scale (Fig. 1) as well as aerial photographs on a scale of 1:50,000 provided the basic framework (Fig. 2) of this study. Plane table mapping was carried out on a large scale varying from 1:400 to 1:1000 to plot the individual dune shapes and to ascertain the nature of the topography. Repeat profiles across the sand movement

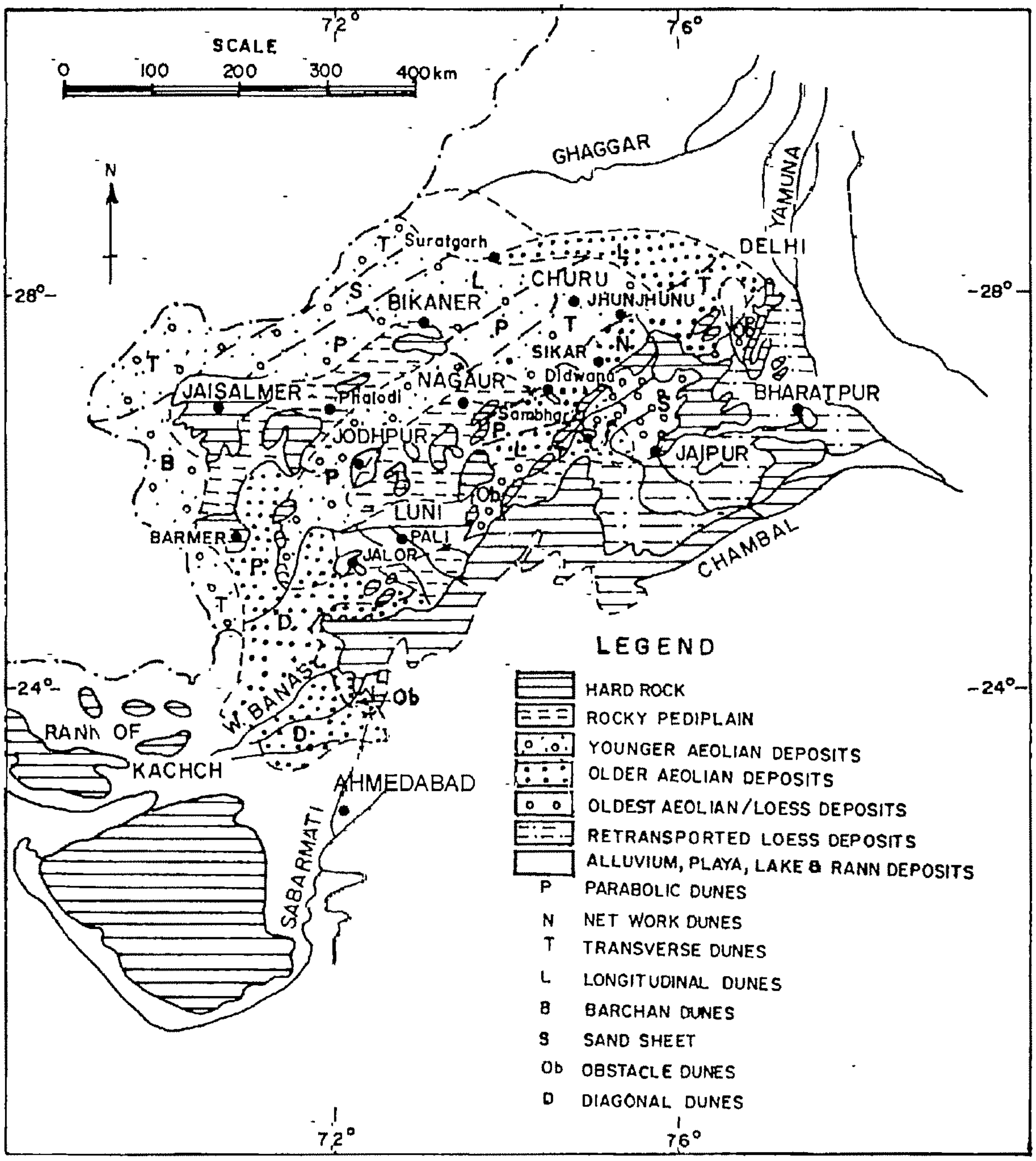

**Fig. 1.** Distribution of aeolian sediments and dune forms of the Thar desert, Rajasthan, India

direction were surveyed. Pits and trenches were made in recent dune fields to reveal the underlying substratum and measure the amount and direction of the cross dip. Rose diagrams were prepared to infer the wind regime and wind direction (Fig. 3-5).

## *Geology and Geomorphology*

The western and southeastern parts of the Thar desert are covered mainly by Precambrian formations forming hill ranges and broad flat valleys with a NNE-SSW trend. The western and eastern parts of these hills comprise rocky pediplains at different altitudes with the development of shallow depressions. These shallow depressions are filled up with Quaternary fluvial, lacustrine and aeolian sediments. Towards the west, around Jaisalmer, the Precambrian basement is covered by Mesozoic and Tertiary sandstones, limestones, shales, siltstones and conglomerates (Goudie and Thomas 1986; Wason and Hyde 1983;

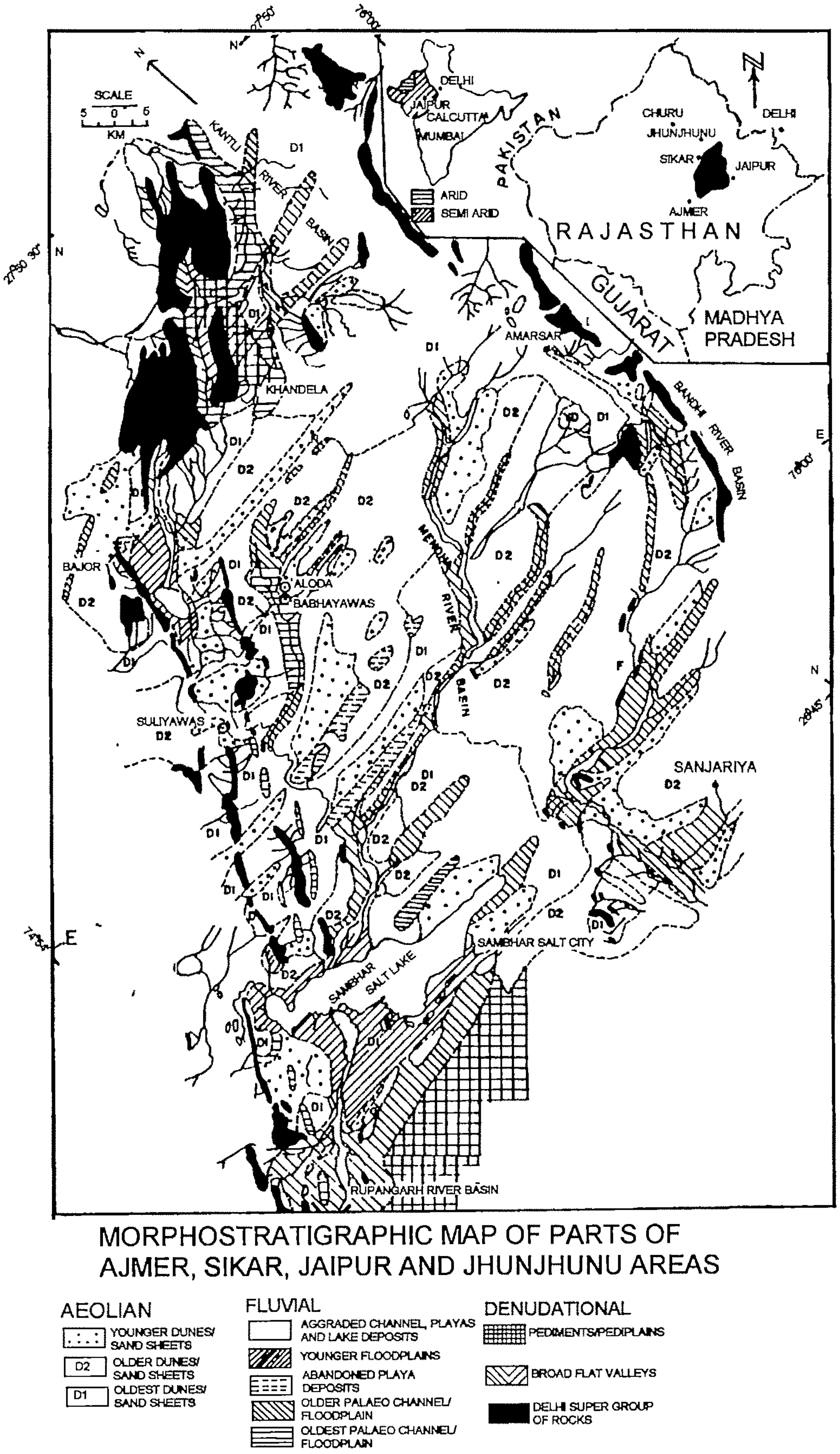

**Fig. 2:** Morphostragraphic map of parts of Ajmer, Sikar, Jaipur and Jhunjhunu areas

Wasson *et al.* 1983; Pareek 1987). These Tertiary and pre-Tertiary sedimentary rocks have given rise to a vast rocky pediplain or *hamada* (Dhir *et al.* 1992).

This area of bedock outcrop is deeply dissected with the development of broad valleys. During the Quaternary period these broad valleys have been converted to depositional basins due to neotectonism and the onset of aridity in the area.

Raghav (1992a) and Raghav and Sinha (1998) have identified three cycles of sedimentation during the Quaternary period from the Jaipur upland area. Each cycle commenced with a fluvial phase followed by a transitional playa stage culminating in an aeolian phase and are labelled, the oldest aeolian deposits (A1), older aeolian deposits (A2) and younger aeolian deposit (A3).

The dunes of the first phase (A1) are present in the form of obstacle dunes around hills, longitudinal and transverse sand ridges around the depressions, playas and lake areas and form the flatter topography in the sand sheet area. The topography of this phase had been greatly modified by later aeolian and fluvial erosion and accretion. The dunes and the sand sheets have been dissected by the gullying (Fig. 2).

The dunes of the second phase (A2) are stabilised and covered by those of the later phase (A3). They occur in longitudinal, transverse, parabolic and obstacle shapes (Fig. 1). At some places these are undergoing gully erosion. The present topographic features of the terrain are mostly controlled by the dunes of this phase. In addition to the Sambhar salt lake in the southern part of the area, several abandoned lakes, playas, shallow depressions and ponds are confined to the widely spaced interdunal fields. They generally form broad flats with or without a faint slope towards the central part. Bordering dunes in this area, have steeper slopes on the northern sides and gentle slopes on the southern sides. The interdunal depressions are more or less rounded or oval and elongated in an E-W direction (Fig. 1).

The third phase comprises longitudinal transverse, parabolic, barchanoid and obstacle types of dunes (Fig. 3). These are under the processes of accretion, erosion and stabilisation depending upon the process dominant in the area.

The active dunes of the third phase are barchanoid, longitudinal, linear, transverse, parabolic and star shapes. They occur at the top of the older dunes, along the courses of the present aggraded rivers, around the lakes, playas, shallow depressions and against obstructions such as hills, settlements and constructions (Fig. 1).

### *Mophostratigraphic distribution of parabolic dunes*

A large area of the Thar desert is covered by parabolic dunes in regions ranging from 100 to 500 mm rainfall (Fig. 1). Many scholars (Verstappan 1970; Breed and Grow 1979; Singh 1982; Wasson *et al.* 1983; Dhir *et al.* 1992; Wadhwan 1994, 1998) have described the different forms of dunes from the Thar desert.

The present study reveals that the parabolic dunefields which have developed in the Thar desert and its fringe area belong to different aeolian episodes. The parabolic dunes of Didwana and Sikar District belong to the second aeolian episode (A2). Presently, these parabolic dunes have been superimposed by active parabolic, transverse, linear and barchan dunes. These parabolic dunes are intermixed with a network of dunes further to the northeast in Sikar District. The thickness of parabolic dunes varies from 1.5 to 10 m on the limbs and 5 to 30 m on the nose. The parabolic dunes of Barmer and the southern part of the Shergarh area are stabilised dunes of the third aeolian episode (A3). Toward the southwest and northeast, these dunes are also superimposed by dunes of transverse, longitudinal and barchan shapes. In this area, the parabolic dunes overlie the earlier aeolian and fluvial sediments which form an undulating type of substratum.

The parabolic dunefields of Lunkaransar, west and northwest of Bikaner and southwest and south of Umarkot also belong to the third aeolian episode (A3) which is associated with linear, transverse and barchan types. These dunes are active parabolic dunes which are overlying the older flood plain and distributaries of the Indus River system. Some active parabolic dunes are also developing over the rocky pediplain northwest of Pokharan and between Barmer and Jaisalmer. These dunes are associated with a sand sheet. Wasson *et al.* (1983) have described clusters of linked parabolic dunes from these areas. These clusters of parabolic dunes develop in the presence of vegetation due to wind scour in the alluvium and once the parabolic forms are developed the dune moves forward.

Parabolic dunes near Shergarh have rounded noses in contrast to the hairpin parabolic dunes between Barmer and Jaisalmer and southwest and south of Umarkot. Lunate dunes occur in the Churu area on the eastern side of local depressions.

To understand the evolutionary process in the development of parabolic dunes, detailed mapping was carried out with a plane table followed by pitting and trenching in the following areas.

### *A Suliyawas parabolic dune of Sikar*

Satellite imagery (1:1,000,000 scale) indicated the presence of a network type of dunefields comprising longitudinal and traverse dunes but on aerial photographs (1:50,000) these dunes were found to be coalesced parabolic dunes. As a part of the field study a plane table survey was carried out to map one such parabolic dune lying west of Suliyawas village in Sikar District (Fig. 2). The thickness

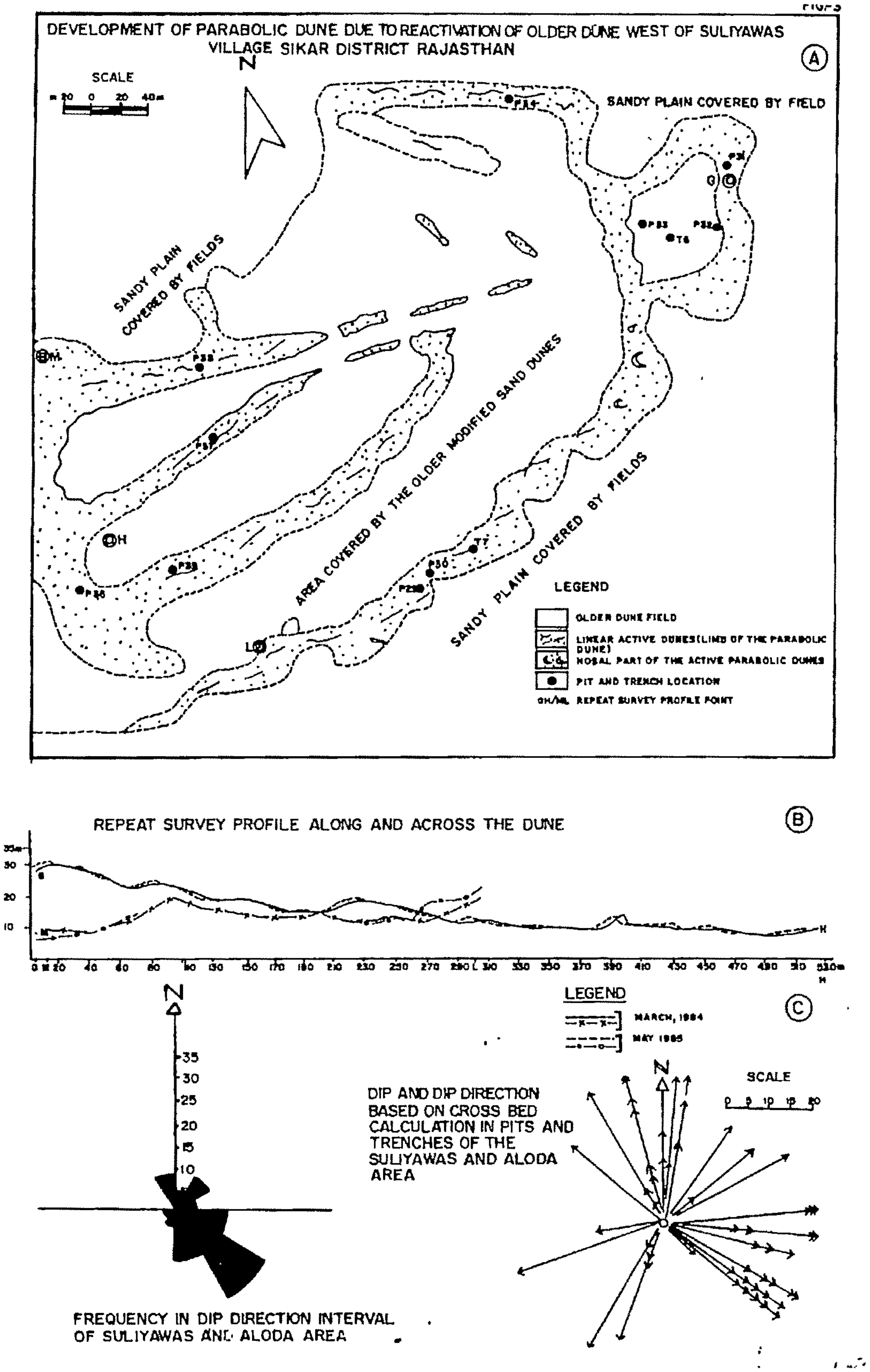
DEVELOPMENT OF PARABOLIC DUNE DUE TO REACTIVATION OF OLDER DUNE WEST OF SULIYAWAS VILLAGE SIKAR DISTRICT RAJASTHAN
Ⓐ
N
SCALE
20 0 20 40m
SANDY PLAIN COVERED BY FIELD
SANDY PLAIN COVERED BY FIELDS
AREA COVERED BY THE OLDER MODIFIED SAND DUNES
SANDY PLAIN COVERED BY FIELDS
P31
P32
P33
P34
P35
P36
P37
P38
P29
P30
T6
T7
G
M
H
L
LEGEND
OLDER DUNE FIELD
LINEAR ACTIVE DUNES(LIMB OF THE PARABOLIC DUNE)
NOSAL PART OF THE ACTIVE PARABOLIC DUNES
PIT AND TRENCH LOCATION
GH/ML REPEAT SURVEY PROFILE POINT
REPEAT SURVEY PROFILE ALONG AND ACROSS THE DUNE
Ⓑ
35m
30
20
10
H
LEGEND
MARCH, 1984
MAY 1985
Ⓒ
N
35
30
25
20
15
10
FREQUENCY IN DIP DIRECTION INTERVAL OF SULIYAWAS AND ALODA AREA
DIP AND DIP DIRECTION BASED ON CROSS BED CALCULATION IN PITS AND TRENCHES OF THE SULIYAWAS AND ALODA AREA
N
SCALE
0 5 10 15 20

**Fig. 3**: Development of the parabolic dune at Suliyawas village, Sikar District, Rajasthan

of recent aeolian sediments contributing to the parabolic dune is 30 m on the nose but varies from 1.5 to 4 m on its limbs (Fig. 3). It is observed that there are two sets of the parabolic dunes within one major parabola which are the product of a combination of linear and barchan dunes whereas the central and nose parts are covered by transverse dunes. Linear dunes are common on the limb part along with barchans and transverse dunes.

The length of these two parabolic dunes are 300 m and 550 m whereas widths are 100 m and 350 m respectively (Fig. 3).

A total of 24 pits and 8 trenches were made around the different part of the Suliyawas parabolic dunes. This study reveals that parabolic dunes are superimposed over the older stabilised dune. Cross bed data plotted in Figure 4 indicates that westerly winds are more dominant in the nose whereas westerly, northwesterly and southeasterly winds are dominant in the limb of the parabolic dune (Fig. 3). The sand supply on the limb is restricted due to the presence of an older linear ridge (A2) which interfaces with the winds. However the sand supply on the nose is comparatively higher owing to a prevalent strong westerly wind (Fig. 3).

Repeat profiling along the MN direction across the arms indicates erosion on the northern and accretion on the southern arms. Local reactivation of sand is indicated and the rate of migration of the parabolic dune further eastward is very slow. No vegetation cover was observed on the arms of the parabolic dunes. The ground water depth is 60 m in this area.

*Aloda parabolic dune of Sidar*

This is a reactivated parabolic dunefield belonging to the second aeolian episode. Here the parabolic dunes are overlain by linear and barchan active dunes on the limb and transverse and brachan dunes on the nose (Fig. 4). The northern limb of the parabolic dune is bounded by an older pan. The length of the southern and northern arms of the parabolic dune are 500 m and 300 m respectively and the width is 300 m. The height of the parabolic dune ranges from 10 to 30 m at the centre of the nose and 10 to 20 m in the limb area. A large scale (1:800) plane table contouring was carried out around the reactivated northern limb of the parabola to delineate the shape of the superimposed active dunes. The active dune height varies from 2.0 to 5 m. These dunes are coalesced barchans with an aeolian sand sheet spread in the down wind direction A total of nine pits and trenches of 1.5 to 2.5 m were made in the different parts of the dune. The crossbed data of these pits is plotted in Figure 4 indicating the dominance of southwest, westerly and northwesterly winds in the area. This is also seen by the presence of a slip phase over the active dunes. The repeat survey profile across and along the AB band and CD profile line indicate that the accretion of sand is greater on the northern and central parts whereas the western and southern parts of the older dunefield has suffered erosion (Fig. 4).

*Parabolic dune east of Abhayas Village, Sikar District*

Here an active parabolic dune is formed by the associations of barchan, linear and sand sheets in the area of an older reactivated field (Fig. 2). Three linear active sand accretion zones are linked by the contemporary barchan dune. The plane table mapping of this active zone indicates the formation of parabolic dunes. The dune heights vary from 1.0 to 4.5 m Repeat survey of cross and along profiles indicate that the accretion of sand is greater on the crest of the linear and barchan dunes (Fig. 5). A total of 12 pits were made in the area. The dip direction and dip amount of cross beds were plotted (Fig. 5) which indicate the prevalence of westerly, southwesterly and northwesterly winds in the area.

## Discussion

The present study brings out the influence of the landforms of the underlying substratum, sediment characteristics and moisture content in the formation of varied forms of parabolic dunes and their relationship with the other associated dune shapes. It was observed that a variable amount of sand availability, wind regime, and the nature of the topography have caused the formation of varied morphological forms of parabolic dunes. One of the authors (Raghav 1992), has classified the shifting dunes broadly into dune shapes associated with flat topography and dune shapes associated with undulating topography.

A large number of combinations are observed in the formation of parabolic dunes from transverse sand sheets, barchans and longitudinal dunes depending upon the degree of control exerted by sand supply, wind speed and direction, and the local geographical setting (Fig. 6). Vegetation and moisture content play an important role in the modification and stabilisation of the individual dune forms. The parabolic dunes occur over flat topography in the flood plain and the deltaic parts of the Indus River and its tributaries and distributaries.

The rocky pediplain area south and north of Jaisalmer has hairpin parabolic dunes. Verstappen (1972) has described such dunes as fork shaped. The area of the fork always points windward and the stem leeward. Several hypotheses have been proposed for the formation of these dunes. An early and recently referred to hypothesis (Dhir *et al.* 1992) suggests that the dunes are stationery residual features analogous to yardungs formed by wind erosion of sand in the interdunal depressions (*gassi*). Dhir *et al.* (1992) have described a gradual change in the shape of longitudinal dunes towards the east which have produced

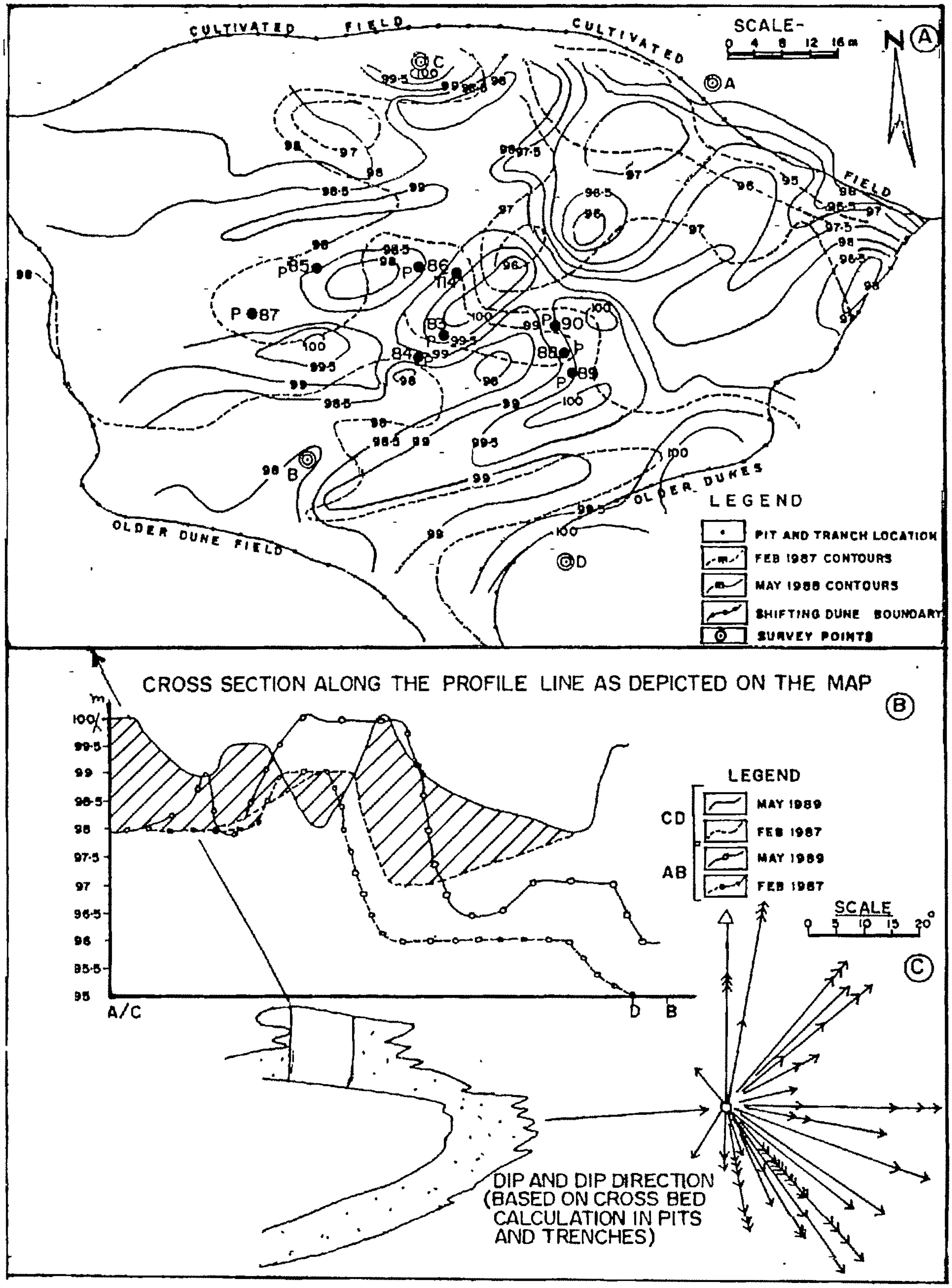

Fig. 4: Survey on the northern limb of the shifting parabolic dune east of Aloda

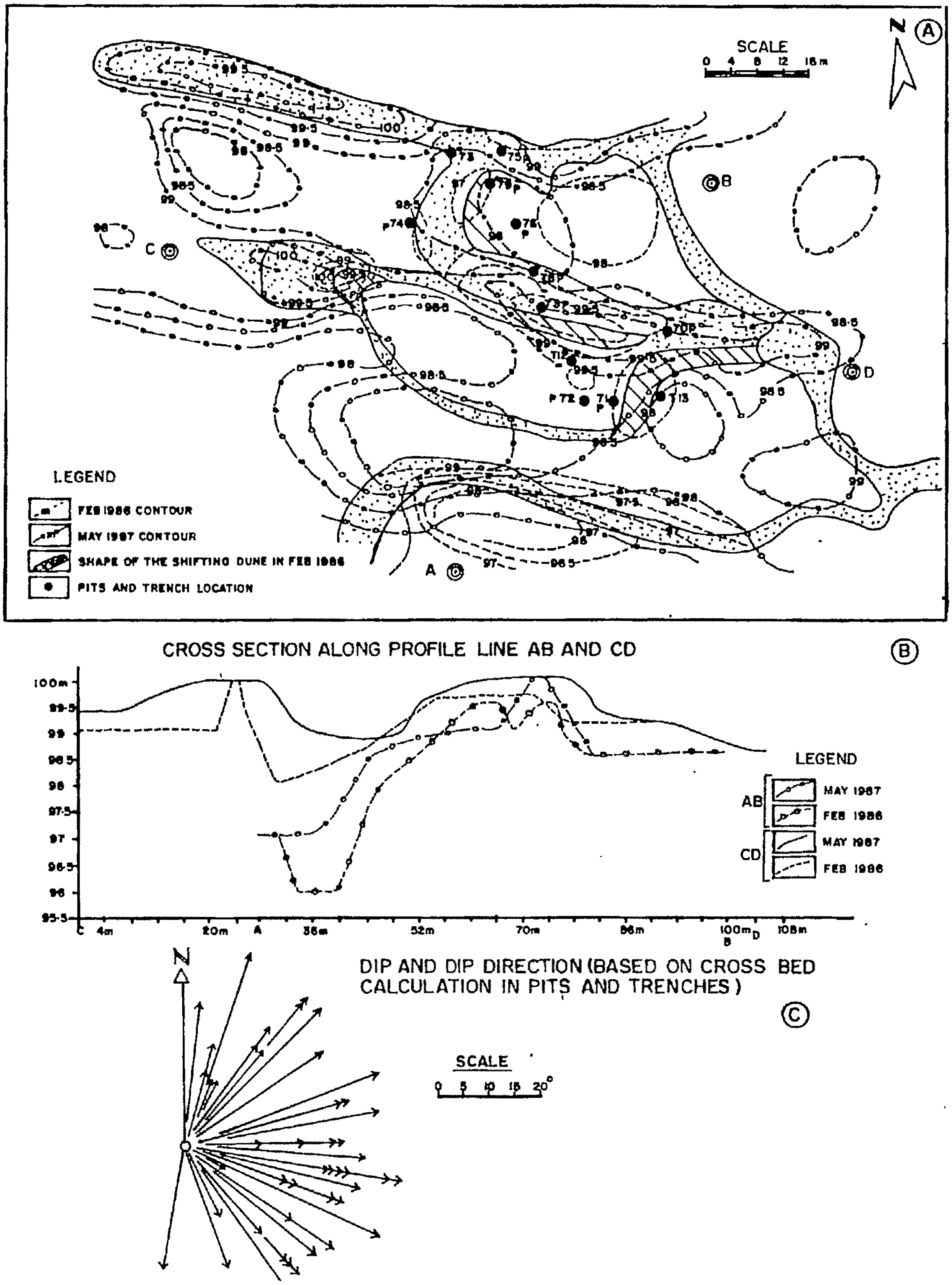

**Fig. 5**: Repeat survey of shifting dune east of Abhaybas, Sikar district, Rajasthan

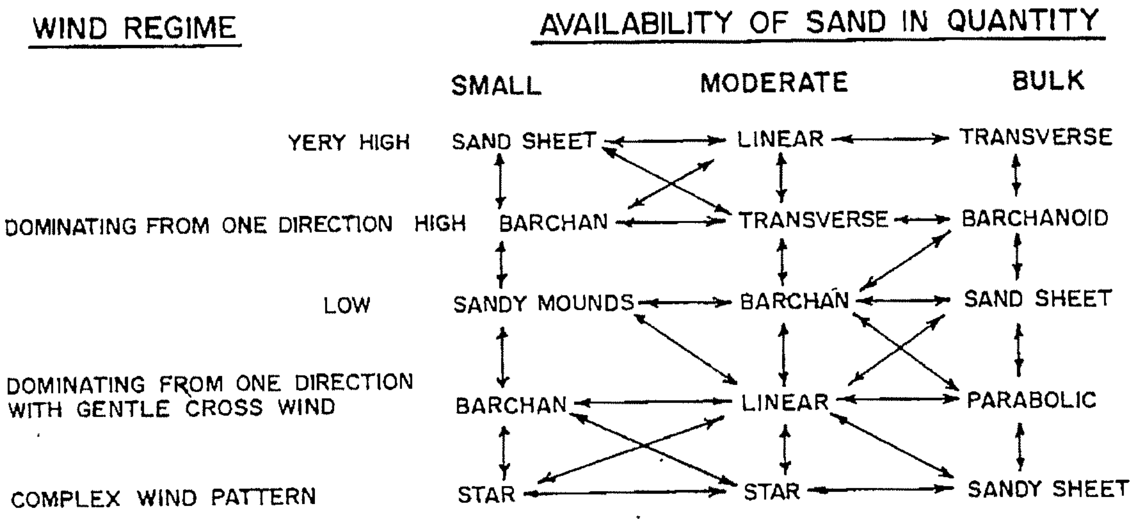

**Fig. 6**: Possible change of one dune shape to another

inverted Y junction clustering of longitudinal dunes which merge with parabolic dunes further east.

However the present study suggests that these dunes have developed due to the morphological variations in parabolic dunes which have developed over undulating types of substrata. These undulations occur in the form of rocky and sandy mounds formed by palaeodunes and palaeoriver courses. The alignment of these undulations along, across and oblique to the wind speed and direction and their association with varying sand masses can cause formation of all six types of Y junctions.

The parabolic dunefields of Barmer, Shergarh, Churu and Sikar Districts have developed over dunes of the older aeolian episode. These dunes have formed due to the reactivation of the older dunes (Fig. 1). The ridges of these older dunes have been obliterated with the formation of linear and barchan dunes.

The interdunal depressions of these dunes are occupied by transverse and barchan dunes in the prevailing conditions. The association of all these dunes can cause the formation of a parabolic dune (Fig. 3). Singh (1982) also described the association of simple parabolic dunes with transverse ridges.

The lunate dunes (clay dunes) of the Churu area on the eastern side of local depressions are also formed due to the presence of undulations in the form of palaeo-banks. These banks and the area in between are covered by linear, transverse and barchan dunes which have caused the formation of lunate shapes. The present study suggests that all the different shapes of parabolic dunes can form by similar processes of the association of linear, barchan and transverse dunes as the sand supply, wind regime and nature of the underlying landforms varied in a local geographical setting.

## Conclusions

The nature of the underlying substratum plays an important role in the formation of the parabolic dunes. The development of varied morphological shapes of the parabolic dunes are controlled by variation in sand supply, wind speed, wind direction, and the nature of the substratum. The rounded nose parabolic dunes in the Thar desert are developed over the older aeolian episode dunes whereas hairpin parabolic dunes are developed over rocky pediplains. These dunefields are associated with transverse, linear, barchan dune and sand sheet deposits in varied geographical settings. A number of combinations are possible which result in the change of parabolic dune shapes to others and vice-versa with the change in prevailing conditions of sand supply, wind regime and the nature of substratum.

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# Quaternary Geology and Stratigraphy of the Shergarh–Dechu Sub-Basin Along the Eastern Margin of the Thar Desert, Rajasthan, India

S.K. Wadhawan

Geological Survey of India
Jaipur 302 004

## Abstract

The Shergarh–Dechu sub-basin occurs along the eastern margin of the Thar desert and forms the western parts of Jodhpur District, Rajasthan. Episodic multi-phase aeolian deposits are distinguished resting disconformably over fluvio-aeolian and calcretised colluvio-fluvial units in the basin. Presently four major lithostratigraphic formations have been defined. The Quaternary lithostratigraphic framework, with details on litho-contents, boundaries and relationships with the overlying and underlying formations are enumerated. This synthesis provides for morpho- and climato-stratigraphic interpretations.

## Introduction

In order to carry out detailed qualitative and quantitative geologic and geomorphic studies of the Quaternary continental deposits, it is not only convenient, but also desirable to adopt the concept of a basin or sub-basin with reasonably well defined phases of degradation (erosion) and aggradation (deposition). It is recognised that the basin scale approach can provide a meaningful framework for interpreting the litho-stratigraphy and morpho-stratigraphy of the desert sedimentary environments, aeolian bedform hierarchy, grain-size patterns and the sediment flow characteristics vis-à-vis the evolutionary trends in the causative wind regime. It has been feasible to distinguish a few large and broadly linear Neogene sub-basins or tectonic depressions filled-in with Quaternary sediments and separated from each other by denudational relief features or barriers in the arid and semi-arid western parts of Rajasthan (Wadhawan 1991). Based on detailed field surveys, geological mapping of Quaternary formations, the nature of surface disposition and inferred sub-surface configuration in the Thar desert in western Rajasthan, it is possible to delineate a few Quaternary/Neogene sub-basins as are shown in Figure 1. These inferred Quaternary continental sedimentation basins in the western Rajasthan desert include the following:

1. Merta-Degana-Chhajoli (Jayal) sub-basin, on the eastern fringe of the Rajasthan desert;
2. Bikaner-Churu-Ganganagar sub-basin; part of the Ghaggar basin in the northern parts of the Rajasthan desert;
3. Shahgarh-Kishangarh sub-basin in the western parts of the Rajasthan desert;
4. Shergarh-Dechu sub-basin in the central parts of the Rajasthan desert.

The Neogene tectonic movements that ostensibly formed a series of parallel horst and graben structures, generally trending NE-SW, are considered responsible for controlling the architecture, configuration and development of various lithofacies in these continental basins of deposition (Ahmad 1969,1986; Ahmad and Ahmad 1980; Sinha-Roy 1986; Dassarma 1986, 1988; Ramasamy *et al.* 1991). In order to evaluate and develop a correlative stratigraphic model for the Quaternary evolution of different sectors of the Thar desert in Rajasthan, it is imperative to understand the lithological and sedimentological details and evolutionary history of each of these delineated continental sub-basins for which some initial attempts have been made (Rai 1990; Wadhawan 1991; Wadhawan and Sural 1992; Dhir *et al.* 1992; Chamyal 1995; Sundaram *et al.* 1996; Wadhawan and Sharma 1997). The Shergarh–Dechu sub-basin of Quaternary sedimentation is important for two other reasons. First, the characteristic aeolian landforms of the Thar desert, clustered parabolic dunes are found in this basin and secondly, a variety of desert sedimentary environments, constituting the present-day active desert front are present. This basin experiences aeolian dynamism thus offering opportunities for understanding the processes of desertification and inferring trends in landform evolution on the basis of observations of ongoing processes. This sub-basin also delimits the northeasterly extension of

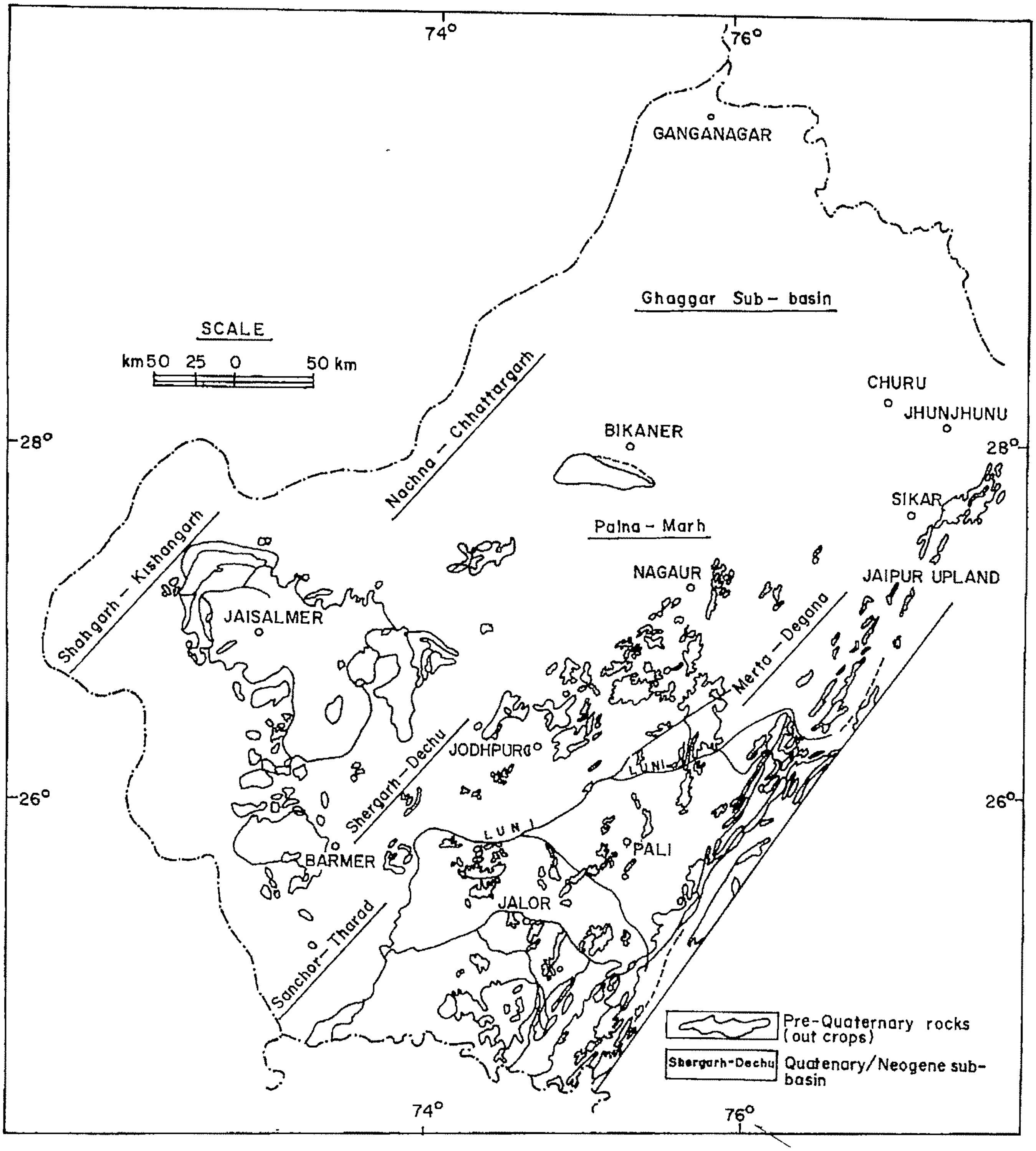

**Fig. 1**: Spatial disposition of Quaternary/Neogene continental sub-basins in the Thar desert, western Rajasthan

the vast and characteristic clustered parabolic dune fields of the Thar desert. It is also remarkable that the core of the aeolian belt is largely confined to the Quaternary alluvial basin showing that the availability of a proximal source of sand is an important factor in dune construction.

## Quaternary Geology and Stratigraphy of the Shergarh–Dechu Sub-basin

The Shergarh–Dechu Quaternary geologic continental sub-basin occupies the western parts of Jodhpur District in Rajasthan. It is characterised by episodic multi-phase aeolian deposits resting disconformably over fluvio-aeolian and calcretised colluvio-fluvial deposits of Early Quaternary (Neogene?) age. These deposits occur in a NE-SW trending broadly linear configuration, bound on the west by the Pokaran-Bap-Bikaner rocky flat (*hamada*) and the boulder/gravel strewn serir plain or the gibber flat. They are flanked on the east by the residual hills of Malani rhyolite and the dissected plateau over the sandstones of the Marwar Supergroup girdled by attendant colluvial aprons of slope-wash clastic debris and intermittently exposed pediments. Quaternary fluvial sediments in the Shergarh–Dechu sub-basin form the northern and north-eastern part of a larger Quaternary continental basin that was ultimately, through the structurally controlled southerly flowing river basin, draining into the palaeo-Luni, and so a tributary to it. A detailed characterisation of the various desert sedimentary environments is attempted in this sub-basin with the view to construct a model of sedimentation history (lithostratigraphy), to form a framework of morphostratigraphy, and to infer trends of desert landform evolution. Field surveys, strata-log inventory of different dug-wells/pit sections, data interpreted from the vertical aerial photo-coverage of the area and petrographic studies of the representative formation specimens were utilised for achieving the following results.

## Framework of Lithostratigraphy and Nomenclature

For an objective classification of Quaternary rocks it is important that the actually visible rock/sediment units be considered for evaluation of their lithological content and finally utilised for making inferences as to the climatic conditions under which they were deposited (Bowen 1978). Lithological character is the prime consideration for lithostratigraphy. The mode of origin or age of a lithostratigraphic unit are relatively unimportant and not considered while assigning lithostratigraphic status to a rock unit/package of sediments (Geological Survey of India 1971, 1982). The cardinal requirement of a basic unit, such as a Formation, is that it should be capable of being mapped as a tabular body of rock strata (with specific lateral extent). However, for a better understanding of geologic history, some formations have been subdivided into members with a distinctive set of lithologic properties. It may be mentioned that although morphostratigraphic units are of informal status only, yet their specific relationship with lithounits is well recognised. Thus a morphostratigraphic unit can be defined as "a body of rock that is identified primarily from the surface form it displays" (Willman and Frye 1970 quoted in Bowen 1978). It includes both landform and lithology and enhances the details of its expression as a geological-cum-geomorphic unit

Quaternary lithostratigraphy in the area of study is constructed on the basis of field relationships, order of superposition of the different strata, degree of consolidation and oxidation of sediments, pedogenic modifications, morphostratigraphy and the nature of associated archaeological artefacts. An apposite code of nomenclature is adopted for a comprehensive interregional correlation. Quaternary geological mapping was carried out on the scale of 1:50,000 and in parts on 1:250,000 during the present study. A synthesised map was compiled on a 1:250,000 scale (Fig. 2). Presently four major Quaternary sedimentation units have been classified into formations that may also provide the basis for morpho- and climato-stratigraphic characterisation. A synoptic scheme of lithostratigraphic framework in the Shergarh-Dechu sub-basin is given below. Deposition of various Quaternary lithounits encountered in dug-well and pit-sections in the area investigated are depicted in Figure 3.

The four formations with their members are summarized below:-

### (I) Phalsund Formation

*Type/Reference Sections:* Phalsund (Dhandhaniya, Madhpura)

*Maximum thickness:* 40 m (mostly subcrop, exposed 4 m)

*Litho-contents:*Calcretised polymictic conglomerates with reworked ferricrete and calcrete and mottled sandy loam/ sandstone /claystone.

*Nature of Contacts*: Lower contact is sharp with lithomargic clays over Malani rhyolite and duricrusted Jodhpur Sandstone. The upper contact is disconformable with gypcrete- clays (Thob Rann); consolidated aeolian sands (Madhpura) and greenish yellow sands (Phalsund).

*Remarks:* This formation comprises two Members, the Dhandhaniya conglomerate and Balesar-Belwa mottled sandy loam with rhizoconcretions. It occurs mostly as valley-fills and aggraded sandy plains.

### (IA)Dhandhaniya Lower Conglomerate Member of the Phalsund Formation

*Type/Reference Sections:* Dhandhaniya (Phalsund, Madhpura, Pilwa)

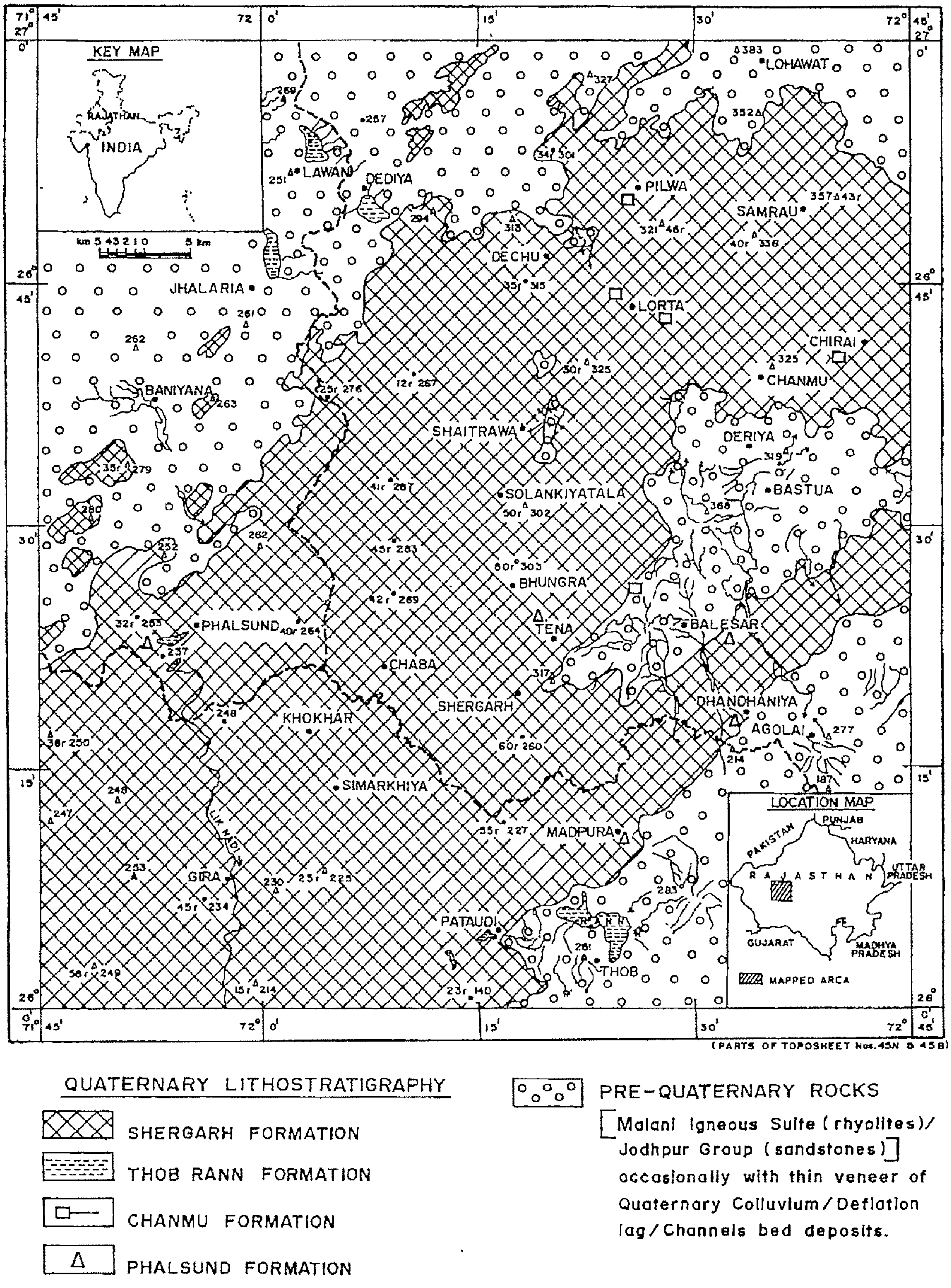

**Fig. 2:** Quaternary geological map of the Shergarh- Dechu sub-basin along the eastern Thar desert margin in Rajasthan

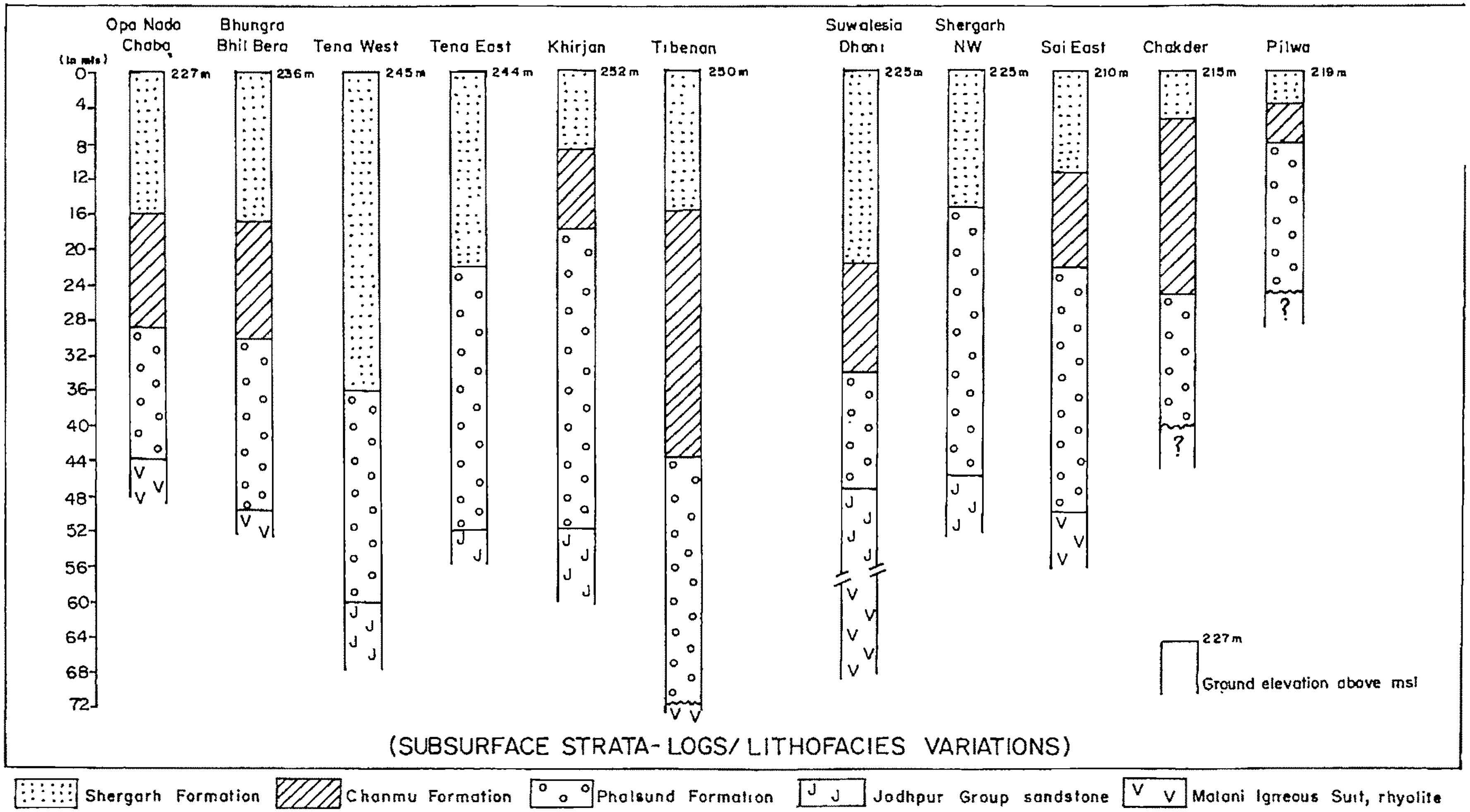

**Fig. 3**: Quaternary lithostratigraphic logs in the Shergarh - Dechu sub-basin showing spatial disposition of different mappable litho-units (Formations) in the area

*Maximum thickness:* 20 m (cumulative)

*Litho-contents*: Cemented gravelly sands/calcretised gritty to pebbly conglomerate and boulder sands.

*Nature of Contacts*: The lower contact is sharp and irregular with duricrusted Jodhpur Sandstone/ Malani rhyolite and its weathered derivatives such as lithomargic clays. The upper contact is gradational and disconformable with mottled sandy loam/consolidated aeolian sands/rann clays and gypcrete.

*Remarks*:These are mostly basal conglomerates marking the commencement of Quaternary continental sedimentation and are commonly encountered in dug-wells and deep pit sections.

### (IB) Balesar-Belwa Upper Mottled Sandy Loam/Clays and Silt members of the Phalsund Formation

*Type/Reference Sections:* Balesar-Belwa (Madhpura, Pilwa; subcrop exposures in Tena, Shergarh, Tibenon areas)

*Maximum Thickness:* 20 m (cumulative)

*Lithocontents:*Sandy loam, clayey sandstone, green-red-orange mottled with ubiquitous rhizoconcretions (greenish-grey ramifications of root-like network).

*Nature of Contacts:* The lower contact is gradational with polymictic conglomerates of the Dhandhaniya Member and the upper contact is disconformable with greenish grey silty loam or sharp with inter-layered gypcrete silty clays and consolidated aeolian sands respectively.

*Remarks:* This member occurs confined to aggraded plains and is mostly encountered in dug-wells where it occurs as a very good high yielding aquifer.

### (II) Chanmu Formation (Colluvio-Aeolian Complex and Sandy Loams)

*Type/Reference Sections:* Chanmu, Lorta-Chirai, Pilwa, Bhojas, Khidan-Balesar Trijunction

*Maximum Thickness:* 20 m (6 m exposed)

Lithocontents: Sandy silts and sandy loams impregnated with calcrete/lumpy kankars, yellowish-green sandy loam and colluvio-aeolian interlayered deposits.

*Nature of Contents:*The lower contact is sharp and disconformable with indurated calcrete pans/gravelly sands (sandy grits and pebble conglomerates) and the upper contact is sharp and disconformable with fine well sorted consolidated and pedogenised aeolian sands of the Shergarh Formation.

*Remarks:* This member occurs as a fairly well spread massive sand sheet over fluvio-aeolian aggradational plains. Lumpy kankar impregnation and hard calcareous sand aggregation/cementation are amongst the most important post-depositional modifications. It comprises two Members, the Khirjan Member (Trijunction) of interlayered colluvial debris/calcified aeolian sands and the Lorta sandy silt/loam Member, representing the proximal and distal end-members of a fluctuating semi-arid environment of deposition.

### (IIA) Khirjan-Balesar (Trijunction) Colluvio-Aeolian Heterolithic Member of the Chanmu Formation

*Type/Reference Sections:* Khidan-Balesar (Trijunction), Rata Bhakhar

*Maximum Thickness:* 7 m (exposed)

*Litho-contents:* Alternating succession of colluvium debris slope-wash beds of angular rock clasts (ill-sorted gravel) and beds of weakly consolidated, well sorted fine sands (aeolian) with pervasive pedocalcic pedogenesis resulting in the formation of large white kankars with variable intensity of occurrence.

*Nature of Contacts:* The lower contact is a sharp unconformity with the Malani rhyolite bedrock (Upper Proterozoic) and the upper contact is sharp and disconformable with consolidated aeolian fine sands.

*Remarks:* This formation is developed typically in the vicinity of rocky uplands as a stacked sequence of alluvial fan/cones of colluvium alternatingly interlayered with wind-laid fine sand beds forming obstacle sand sheets. Semi-arid wet and dry fluctuating conditions/interludes are inferred.

### (IIB) Lorta Sandy Silt/Loam Member of the Chanmu Formation

*Type/Reference Sections:* Lorta-Chirai, Pilwa, Bhojaon ka Bas

*Maximum Thickness:* 10 m

*Litho-contents:*Sandy silt and loam, well sorted to poorly sorted, intensely pedocalcified with large indurated kankars/calc-sand aggregates.

*Nature of Contacts:* The lower contact is sharp with calcrete pan/gravelly sands and the upper contact gradational, at places sharp, but disconformable with fine well consolidated sorted sands.

*Remarks:* This formation occurs mostly as sandy sheets forming the sole of the stabilised clustered parabolic megadunes.

### (III) Thob Rann Formation

*Type/Reference Section:* Thob Rann

*Maximum Thickness:* 8 m

*Litho-contents:*Interlayered gypcrete (selenite)-silty clays-saliferous silts and peripheral calcretes in intermontane depressions/depo-centres.

*Nature of Contents:* The lower contact is sharp with polymictic conglomerates of the Phalsund Formation and/or Proterozoic bedrock (Malanis or Marwars) while the upper is mostly obscure but inferred to be disconformable with consolidated aeolian sands.

*Remarks:* The Thob Rann formation represents a unique lacustrine/playa environment of evaporite formation and seasonally fluctuating inputs of sheet-wash/ephemeral fluvial aggradation. Interlayered crystalline gypsum beds indicate desiccating conditions under extreme aridity.

### (IV) Shergarh Formation (Heterolithic)

*Type/Reference Sections:* Shergarh-Phalsund-Dechu areas

*Maximum Thickness:* 85 m (72 m recorded dune height)

*Litho-contents:*It is a heterolithic assemblage of clastic sediments and evaporates. It is dominantly sandy loam with quartzose sands, fine to very fine grained, very well sorted to moderately sorted; consolidated and pedogenised to varying extent, and medium to coarse sandy/silty clays, calcareous at places. Gypcrete, calcretes and marly clay pans are common in local depressions.

*Nature of Contacts:* The lower contact is sharp and disconformable with kankarised aeolian-fluvio sands, gravelly- gritty sands and mottled sandy clays. The upper contact is exposed at or near the surface over a large sandy desert area.

*Remarks:* It is an omnibus heterolithic and widespread formation of dunes and interdunes comprising four distinguishable members: (1) kankarised consolidated fine sands, (2) gypseous silty clays-gypcrete, (3) weakly pedogenised fine sands, and (4) active loose fine sands with lateral facies variation to gravelly sands/sandy loam as ephemeral channel bed deposits.

### (IVA) Dechu Lower Fine Sand Member of the Shergarh Formation

*Type/Reference Sections:* Dechu-Shergarh-Chaba

*Maximum thickness:* 45 m (inferred from stable dune heights)

*Litho-contents:* Fine grained, well sorted, kankarised and consolidated sands in dunes and calcareous fine to very fine sandy loam with lumpy kankars in interdunes.

*Nature of Contacts:* The lower contact is disconformable with calcrete impregnated sandy silts/gravelly sands in aggraded valleys/rocky pediments or *hamada* over Jodhpur sandstones/Malani rhyolites.

*Remarks:* This member is made up of wide-spread stabilised parabolic dunes and interdunes (clustered megadunes) which are deflated and superimposed/overlain by a younger generation of aeolian and playa deposits and filled-in with ephemeral alluvium along deranged channel courses and evaporites in interdune depressions.

### (IVB) Lik Nadi Gypcrete and Sandy/Silty Clays Member of the Shergarh Formation

*Type/Reference Sections:* Lik Nadi, deranged channel course segments Phalsund, Patodi, Lawan-Dediya-Jhalariya ranns

*Maximum Thickness:* 3 m

*Litho-contents*: Gypcrete, marly clays, saliferous or gypseous silty clays and greyish green-yellow sands representing deranged and avulsion channel deposits.

*Nature of Contacts:* The lower contact is sharp with kankarised fine well sorted consolidated sands (aeolian) and cemented/calcretised conglomerates. The upper contact is sharp with weakly pedogenised fine sands (younger aeolian) and interdune sheet wash clayey-silts/loam.

*Remarks:* This member is generally confined to deranged and avulsion channels or depressions/depocentres receiving ephemeral sheet flows during of semi-arid wet interludes. Evaporite facies are moderately well developed as gypcretes and gypseous clays to marly clays with nearly ubiquitous biogenic turbations.

### (IVC) Tena Upper Sand Member of the Shergarh Formation

*Type/Reference Sections:* Tena, Chaba, Suwaliya

*Maximum Thickness:* 30 m

*Litho-contents:* Sand, fine, well sorted (aeolian reworked) weakly pedogenised.

*Nature of Contacts:* Consolidated kankarised fine sands (older dunes) and upper gradational with the loose active fine sands of recent aeolian dynamism.

*Remarks:* Occurs as superimposed/juxtaposed meso-scale transverse and linear dunes assemblages evolving into parabolic/complex dunes. Active sand dunes mostly occur as linear arrays of small barchans over all the older Quaternary formations.

### (IVD) Kheton ki Nadi Sandy Loam Member of the Shergarh Formation

*Type/Reference Sections:* Bhojas (Khirjan), Ghati Nadi (Duda Bera), Gotabar ki Nadi(Bastua/Belwa)

*Maximum Thickness:* 5 m

*Litho-contents:* Sandy loam, ill sorted loose gravelly sands to sandy clays and laminated channel bed sediments/ slope wash debris/rocky colluvium in upper catchment.

*Nature of Contacts:* The lower contact is sharp with consolidated calcified sands of the older aeolians or cemented gravelly sands and basement rocks of Jodhpur sandstone and Malani rhyolite.

*Remarks:* This member is mostly confined to younger flood plains and recent channel beds. Sediments in all ephemeral streams in the area contain reworked aeolian sands and eroded detritus derived from weathered/deflated bed rock.

## Discussion

The Shergarh-Dechu sub-basin of continental sedimentation has preserved landforms and sediments responsive to climate. Some of these are:

1. An extensive aeolian cover reflecting an accelerated wind regime coupled with decreased precipitation; alternating with,
2. morphological and lithostratigraphical units indicating local fluvial redistribution and formation of calcrete/ gypcrete (lacustrine/playa sequences) which indicate interludes of ameliorated climate, during which time sand dunes were stabilised.
3. A major part of the Quaternary period in the sub-basin constituting the presently active desert front has been characterised by fluvial (semi-arid wet) aggradation with the aeolian dynamics appearing only in the later part of the Quaternary.

The present study has revealed that interrelationships of desert river systems and dunes indicate the alternating significance of fluvial (wet) and, aeolian (dry) processes during the Quaternary. These humid to arid climatic changes are seen in the colluvio-aeolian sequence of the Chanmu Formation (Khirjan Trijunction), the desiccation of the deranged Lik Nadi, the interlayered sequence of the crystalline gypsum and silty-clays in the Thob Rann, and the changes from the older parabolic megadune formation to the younger meso-scale and contemporary small-scale dune formation with similarly oriented longitudinal dune elements. These observations allowed interpretations in terms of repeated episodes of intense aridity and secularly declining wind velocity in the aridity affected area in the past.

Ever since the Neogene uplift of the Siwaliks, continental processes began to dominate the newly created/ accentuated basin and relief morphology in Rajasthan. Such movements resulted in the regression of the Tertiary sea from the Mid-Eocene onwards and the formation of lignite and bentonite depocentres. The ensuing wet tropical climate favoured the formation of bauxite/laterite or ferricrete in the region (Sychanthavong and Patel 1987; Sridhar *et al.* 1994). Therefore, the creation of nearly coeval continental structural/sedimentation basins marked the beginning of a major shift in the depositional environments in western Rajasthan. The stratigraphy has been constructed in the Shergarh-Dechu sub-basin primarily on the basis of the relative order of superimposition of strata, extrapolation of sub-surface data and the mutual relationship observed at the outcrop scale including inferences drawn from pedogenic and neotectonic manifestations and superbounding surfaces preserved amongst the multi-tiered aeolian deposits.

The basal Quaternary sedimentation units represent fluvial deposits (Phalsund Formation) made up of ill-sorted boulders and gravels of vein quartz, quartzite and polymictic open framework conglomerates/arkosic grits comprising immature clasts of rhyolite, granite/gneiss, schist, sandstone and limestone, etc. These rest unconformably over the lithomargic clays, weathered rhyolite (Malani Igneous Suite) and sandstone of the Jodhpur Group in the area. These lithounits are widespread but of varying thickness. They were surveyed across the Shergarh-Dechu sub-basin and form subcrop/buried units except for a few exposed sections. Therefore, they lack geomorphic expression save for the intermittently exposed aggraded plains/serir and depressions in the vicinity of dissected uplands, e.g. the Dhandhaniya and Madhpura sites. Such coarse clastic assemblages also suggest rapid/ torrential sedimentation in a neotectonically disturbed region (Wadhawan 1995). At places it is feasible to distinguish polycyclic fining upward successions (e.g. the geological sections at Pilwa), yet this evidence is fragmentary and perhaps local in nature. In the absence of absolute age determinations, these deposits perhaps constitute a Plio-Pleistocene continuum and are correlated with similar litho-assemblages exposed as ridges along Chhajoli-Jayal (Nagaur), Bikaner-Napasar and the Shumar Formation in the Jaisalmer region (Sundaram and Wadhawan 1994).

Towards the upper part of this formation, calc-cemented (micrite and sparite) clay derived from lithomargic soil profiles overlying weathered rhyolites, reworked calcrete nodules derived from duricrusted pediments and limonite coated nodules in matrix supported conglomerates occur. These units suggest local provenance and polygenetic calcretisation in a semi-arid wet climate. Similar fan deposits in the Sabarmati Basin have been tentatively dated to 360 kyr by TL (thermoluminessence) methods (Tandon *et al.* 1997). The process of widespread calcretisation seems to have continued *parri passu* with the seasonal deposition of mottled sandy loam with characteristic rhizoconcretions (Balesar-Belwa Member). Therefore, a younger valley aggradation phase is recorded under a sluggish, low-energy fluvial environment (semi-arid wet) represented by red-orange-green and purple mottled sandy and clayey loam with widespread ramifications of rhizoconcretions (root-casts) and calcareous cement. Outcrops of these deposits at Madpura show a discernible tilt up to 30° of primary bedding towards a southerly direction. Further evidence for the neotectonism in the area include the following:

1. Linearly controlled disposition and differential thickness of the Quaternary deposits in contiguous blocks of continental sedimentation in the Shergarh Dechu sub-basin;
2. Linearly controlled gully erosion of the Quaternary sediments, for instance in the Kheto ki Nadi and Bhojas area;
3. Structural control over the drainage pattern, asymmetric trunk channel disposition, preferred shifting of channels towards western margins of the basins and parallel drainage alignment and the frequent occurrence of nearly straight channel segments within the Quaternary deposits;
4. The presence of well formed joint-sets in the Quaternary fluvial and older aeolian deposits;
5. *En echelon* disposition of north-south aligned inland depressions within the sandstone *hamada* on the northwestern margin of the area (Jhalariya, Dediya and Lawan Ranns) coupled with higher relative relief and greater density of drainage dissection on the east and northeast of these Ranns respectively. These features imply tectonic tilting and strong neotectonic influence on evolution of the landforms in the area.

The lithounits grouped in the succeeding Chanmu Formation comprise fluvio-aeolian sandy loam/sandy silt Member and colluvio-aeolian heterolithic member showing sedimentological characters of ill-sorted coarse sandy loam and well sorted nearly unimodal fine to very fine sands. They indicate a fluctuating fluvio-aeolian environment of deposition. A finer resolution litho-stratigraphy has not been possible because of limitations imposed on data availability by the sand cover. However, the study of gross sedimentological and available geomorphic evidence does support an inference of alternating fluvial and aeolian dominance. A rare section of the colluvio-aeolian complex in the vicinity of upland tracts, near Shergarh Trijunction (Dhir *et al.* 1992), provides a clear geomorphic expression of obstacle aeolian sand spreads derived from extraneous sources repeatedly interlayered with locally derived colluvium/sheet wash deposits. Such features are significant on at least two counts. First the oldest aeolian deposits are recorded from amongst the mixed sedimentation units in the area. Secondly, intense pedocalcic pedogenesis in the form of large nodular kankars dispersed in the aeolian units and petrocalcic encrustations over the colluvia indicate the onset of aridity and the attendant intensification of aeolian dynamism alternated with relatively wetter interludes. At least four such fluctuating dry and wet cycles are recorded in this section. The oldest aeolian episode exposed in this section is TL dated to 70-60 kyr (Andrews *et al.* 1998), though the antiquity of buried aeolian sands in the deeper aggradational domains, encountered in the dug-wells could go far beyond this age. Stable isotope analyses of the caleretes contained in other aeolian deposits interlayered within the colluvia have been age bracketed to (TL and IRSL dates) 55-60, 43-55 and 25-43 kyr B.P., signifying aridity and considerably lower precipitation during these periods respectively (Andrews *et al.* 1998).

The Thob Formation encompasses a sequence of interlayered gypsum — sandy clays — saliferous/gypiferous silts characteristically confined to an intermontane inland depositional environment amongst the residual hills of the Malani rhyolite (Wadhawan and Sharma 1997). It shows a sharp contact with underlying polymictic conglomerates (Phalsund Formation) and/or basement bedrocks and disconformable upper contact with consolidated aeolian sands. It represents a unique lacustrine environment of evaporate formation, receiving seasonally fluctuating fine sediment inputs of sheet wash. Interlayered crystalline gypsum (anhydrite-selenite aggregates) beds indicate desiccating conditions under extreme aridity. Chronologically this litho-association is presently assigned a status younger than or coeval with the colluvio-aeolian complex and the interlayered gypsum represents pulses of enhanced aridity registered as older obstacle aeolian sand sheets elsewhere. It is interesting to note that such a lacustrine environment has survived the onslaught of major aeolian dynamism represented by free and large (clustered parabolic) dunes piled up in the adjoining aggradational sandy plains. This can be explained by the sheltering and wind-shadowing effect of residual hills that surround the rann, attaining higher obstructional relief particularly on its southwest and south - the dominant paths of the sand-laden winds in the area. Sedimentological evidence suggests that the Thob Rann has continued to receive intermittent endorheic fluvial discharges of fine sediments and chemical solutes. It is reasonable to consider that several short-lived interim periods of relatively ameliorated climatic conditions in an over-all semi-arid and arid ambience are responsible for having induced consolidation and calcrete nodule impregnation of the fluvio/colluvio-aeolian complex — the Chanmu Formation in the area.

Older consolidated aeolian deposits, overlying the Chamu Formation, belonging to the heterolithic Shergarh Formation suggest the formation of the oldest anchored and stabilised megadunes of clustered parabolic and combinations of longitudinal and transverse dune types. A bedform hierarchy of aeolian landforms is inferred from superimposed multi-tiered dunes in the area (Wadhawan

1998). The oldest free dunes in the area rest disconformably over the Chanmu Formation sediments of fluvio-colluvio-aeolian mixed origin. The occurrence of draas (megadune forms) indicates aeolian dynamism far more vigorous and widespread than the younger aeolian episodes. Differential rates of dune migration have resulted in successive over-riding and the formation of "nested" parabolic dune morphologies. A major effect of dune formation in the area was disruption and desiccation of the existing drainage courses that were engulfed by the advancing sands becoming deranged and disjointed. As has been mentioned earlier parabolic dune formation involves considerable scouring and deflationary activity in a vegetated sandy terrain where large amounts of sand are shifted downwind and the longitudinal inter-arm deflationary tracts of the parabola are scooped away. The present study has also revealed that longitudinal dune elements are carved concomitant with the development of barchanoids in the downwind tracts, the superimposition and combinations of which ultimately lead to the formation of parabolic dunes. The widespread occurrence of parabolic dunes in the area represent a major phase of aeolian dynamism in the area and has been TL dated to 13-14 kyr B. P., post-dating the Last Glacial Maxima at c. 18 kyr (Chawla *et al.* 1992).

The occurrence of gypcrete and sandy/silty clays along the deranged course of the Lik Nadi, in a milieu of aeolian sands and engulfed by advancing dunes of younger generations indicate high rainfall ameliorated climatic conditions (semi-arid wet) post- dating the major dune forming episode. The reactivated Lik Nadi and other formerly defunct drainage courses struggled to cut through the stabilized dunes and got lost in the sands in the form of cesspools and evaporite pans. Other corroborative evidence for such amelioration of climatic conditions emerges from the gullying and degradation of the megadunes and the presence of microlithic artefacts belonging to the Mesolithic period — 8-7.5 kyr B.P.(Goudie *et al.* 1973) over the degraded surfaces of the stabilized dunes. However, evidence for the existence of any integrated drainage systems in the area are lacking and hence this wet interlude could at best develop interdune ponds and playas and energise only ephemeral endorheic drainage.

In the Thar desert the first post-glacial wet pulse was recorded around 12.8 kyr in lake sediments (Wasson *et al.* 1984). A dry episode during 11-10 kyr interval is also indicated. Considering the evidence of upwelling in the northwestern Arabian Sea, the notion that the Indian monsoon was significantly enhanced around 13 kyr has been suggested by Wasson *et al.* (1983, 1984) and later confirmed by TL dating of the aeolian sediments in the Thar desert by Chawla *et al.* 1992, signifying intensification of the monsoonal wind regime and dune building activities. Further the Holocene is characterized by two moist episodes, the first one beginning between 9.3 and 7.4 kyr and culminating before 6 kyr (termed the Holocene optimum) and the second, less important one peaking around 4.2 kyr. These two stages are separated by an inferred aeolian episode intercalated in the limnological record (Wasson *et al.* 1984). Based on palynological studies and statistical treatment of the monsoonal data, Bryson and Swain (1981) deduced that the total rainfall during 9-6 kyr was up to three times higher than the present. Further, Singh *et al.* (1990) inferred permanent freshwater conditions between 9 and 6 kyr. At c. 3 kyr B.C., an extensive arid phase began (Singh *et al.* 1974) with rapid dune building (Chawla *et al.* 1992) which matches well with the records obtained for Tibet and northern China (Yan and Petit-Maire 1994).

Aeolian accretionary deposits and dunes of younger aeolian episodes (Tena Member) are observed in the area as mobile semi-stable and active crescentic dunes, barchanoids and linear landforms of smaller dimensions and lower height is to interdune space ratio. These dunes have transgressed through calcrete/gypcrete pans/older calcareous hard pan interdunes and occur superimposed over older stabilised dunes with super bounding surfaces or palaeosols (pedocalcic kankar deflation lag deposits) separating them. This aeolian rejuvenation could be equated to the the Pre-Harappan drier phase in the northern parts of the Thar desert, dated to 9.5-5 kyr B.P. as confirmed by pollen analyses of the lake sediments (Singh *et al.* 1972).

Semi-consolidation through bioturbation, incipient pedocalcic pedogenesis of dune sands of this younger generation and sheet wash/inland playa sedimentation, saliferous/gypseous silty clays and clayey loam, mottled fine grained clastics-evaporite sequences of the Ranns of Jhalariya-Dediya-Lawan suggest a milder and short-lived recurrence of amelioration in climate in the area. This higher rainfall episode can be correlated with the Harappan wet phase based on the archaeological finds in the vicinity, near Balotra (Tilwara) on the banks of the river Luni (Singh *et al.* 1972; Goudie *et al.* 1973; Misra *et al.* 1982a, 1982b). However, it needs to be emphasised that ever since the formation of parabolic dunes in the area, no integrated drainage system could thrive and the desiccated desert drainage could at best develop into endorheic ephemeral courses debauching into the inland depo-centers. Palaeoclimatic inferences and correlative geochronology as applicable to the lithostratigraphic framework in the area has been summarised and is shown schematically in Figure 4.

Finally the desert sedimentary environments entered into the realms of the recent seasonal dune building activity of mild intensity with occasional flash floods in the prevalent arid and semi-arid ambience. Reworking of sediments from older aeolian and fluvio-aeolian deposits is

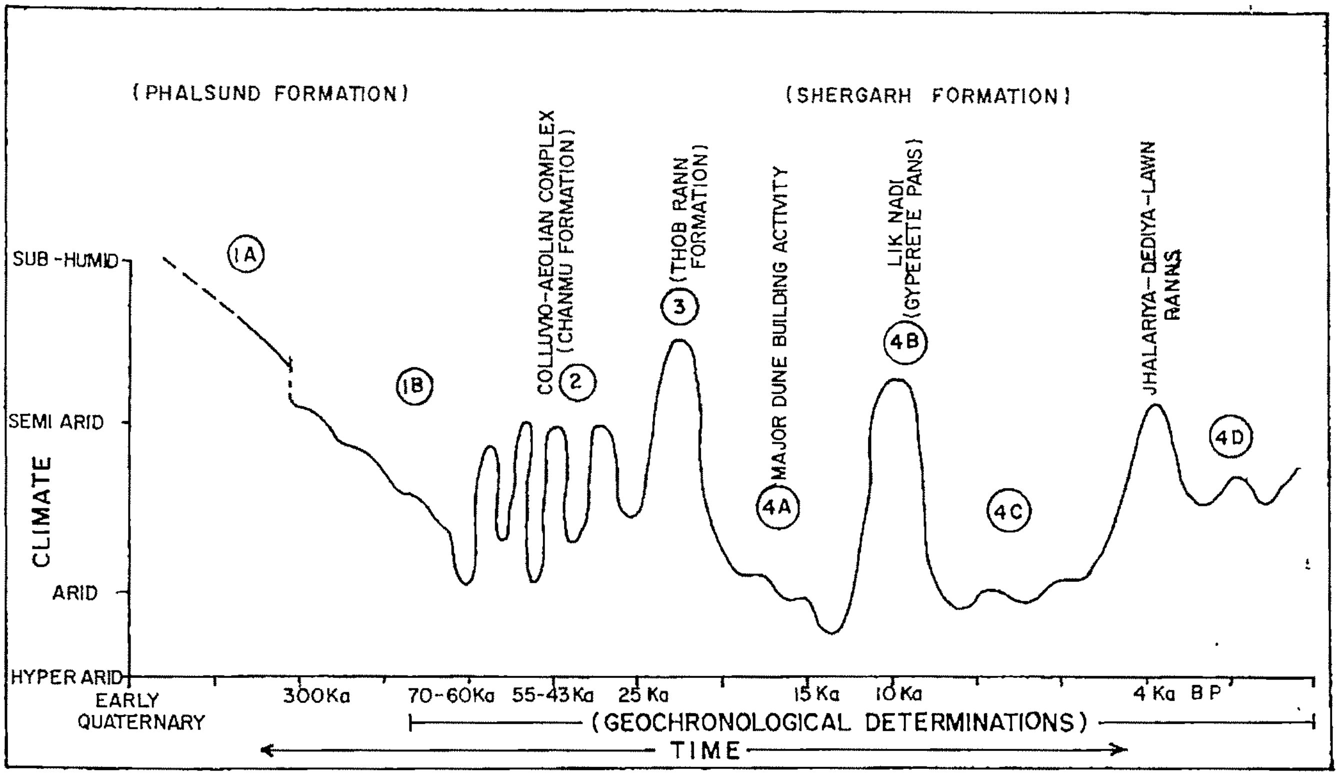

**Fig. 4**: Schematic diagram depicting Quaternary lithostratigraphy, palaeoclimatic inferences and correlative geochronology of the Shergarh-Dechu sub-basin in the Thar desert (Numbers in the circles indicate a succession of Quaternary lithostratigraphic formations). For Members see text

the characteristic feature alongside the eroded/deflated sediment contributions from the locally available rock types in the area (Kheton ki Nadi Member). They are considered younger than the post-Kalibangan and Rangmahal settlements located on the northern periphery of the Thar desert (c. 2900-2000 years B.C.; Lal 1979). Spontaneous dune building/aeolian sand transmission/dune migration activity is presently observed confined to areas west of the 250 mm isohyet in the western and northwestern parts of the Shergarh-Dechu sub-basin.

## Conclusions

Quaternary geological mapping, the preparation of sub-surface geological stratalogs and the study of lithofacies variations in the Shergarh-Dechu sub-basin have led to the formulation of models on lithostratigraphy and morphostratigraphy given above. A lithostratigraphic framework with nomenclature based on type/reference sections has been proposed for an assemblage of (c. 160 m cumulative thickness) multi-phase aeolian deposits (Late-Quaternary/Mid-Pleistocene) punctuated with interludes of playa evaporates/endorheic fluvial sedimentation, resting disconformably over fluvio-aeolian and calcretised colluvio-fluvial deposits of the basal Quaternary stage.

Four mappable Quaternary sedimentation units delineated in the Shergarh-Dechu sub-basin are: (i) the Phalsund Formation with Dhandhaniya Conglomerate/gravely sand Member and Balesar-Belwa mottled sandy loam/sandstone-claystone Member; (ii) the Chanmu Formation comprising two members: The Lorta sandy-silt/loam and Khirjan (Trijunction) colluvio-aeolian units; (iii) the Thob Formation consisting of interlayered gypsum-sandy clays; (iv) the Shergarh Formation (heterolithic) comprising four members — the Dechu lower fine sand, the Lik Nadi gypcrete-sand-silty clay, the Tena upper sand, and Kheto ki Nadi sandy loam units.

It is contended that chronologically the Thob Rann witnessed earlier wetter climatic episodes when palaeochannel courses were through flowing, possibly as tributaries of the river Luni in the south. Neotectonic movements of the younger phase blocked its passage and heralded the lacustrine facies of sedimentation followed by a successive sequence of aeolian deposition in the area. Post-parabolic/megadune wet interludes are represented by inland sabkha environments along the deranged Lik Nadi (Phalsund gypcrete) and the ranns of Jhalariya-Dediya and Lawan in the Shergarh–Dechu sub-basin of Quaternary continental sedimentation.

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# Micromorphology and Geochemistry of Late Neogene–Early Quaternary Ferricretes, Jaisalmer Basin, Rajasthan

Hema Achyuthan

Department of Geology
Anna University
Chennai 600 025

## Abstract

Ferricretes in the Jaisalmer Basin have been formed over the marine Middle Jurassic to Upper Eocene rocks. In this paper these ferricretes have been studied in detail using micromorphology and geochemical analyses. These analyses indicate that they have been formed by the complex processes of pedogenesis and groundwater fluctuations since the Neogene-Quaternary period.

## Introduction

A ferricrete (or hard plinthite) is a massive hard pan horizon enriched and strongly cemented by sesquioxides, mainly iron oxides (MacVicar *et al.* 1977; Bourman 1993a). In the Jaisalmer Basin, duricrusts/ferricretes are conspicuous elements of both the landscape and the stratigraphic column. At many sites they have developed over the marine sandstone and limestone sequences of Middle Jurassic to Upper Eocene age. Ferricrete horizons are plugged or cemented by $CaCO_3$, or ferricretes are overlain by calcretes. In this study, iron cemented and indurated crusts and horizons are referred to as ferricretes. Iron-depleted and iron mottled materials are referred to as bleached and mottled zones respectively. The study of ferricretes is important as, in the Jaisalmer Basin at several sites archaeological material has been found over the ferricrete surfaces which thus predates them (Rajaguru *et al.* 1996; Achyuthan 1998). However, till now no detailed work has been carried out to understand their process of formation.

Ferricretes are exposed at several locations along the rain cut gullies, channels, dug wells and form pediplane surfaces near Sam, Khuiyala, Khian, Sanu, Kudare and Bedesir (Fig. 1).

There are several problems in the investigations of ferricretes.

1. The development of an acceptable terminology to describe the forms and processes associated with ferricrete genesis.
2. Identifying and classifying ferricrete materials.
3. Identifying the mode of formation of the ferricretes. Determining whether it is by in situ weathering, relative or absolute accumulation of iron or by continual weathering and erosion of a long exposed landscape. The relationships of ferricretes to zones of mottled and bleached bedrock and sediment are also critical.
4. Determining the age of ferricretes, their types, the genesis and relationship to the age of the surface on which they have developed.
5. The reliability of ferricrete as palaeoclimatic indicators and their usefulness as morphostratigraphic markers.
6. Identifying the topographic requirements for ferricrete formation.

To seek answers for a few of these questions, micromorphology and geochemistry of ferricretes was studied and the results are presented here. Micromorphology has been used as a tool to distinguish the pedogenic and ground water related ferricretes.

## Field Occurrences and Relationships

Field observations of ferricretes reveal a complex of ferruginous crusts distributed widely and sporadically throughout the landscape in association with a variety of weathered profiles and soils. In the Jaisalmer Basin ferricrete occurs as horizons, crusts and lag gravels occurring on topographically flat, pediplane surfaces. Bleached and iron mottled zones associated with the ferricrete horizons vary in depth and in the size of iron mottles (Fig. 2).

A critical examination of these relationships reveal that the upper part of the surfaces are a complex morphological feature with the occasional projection of unweathered bed rock of limestone and sandstone.

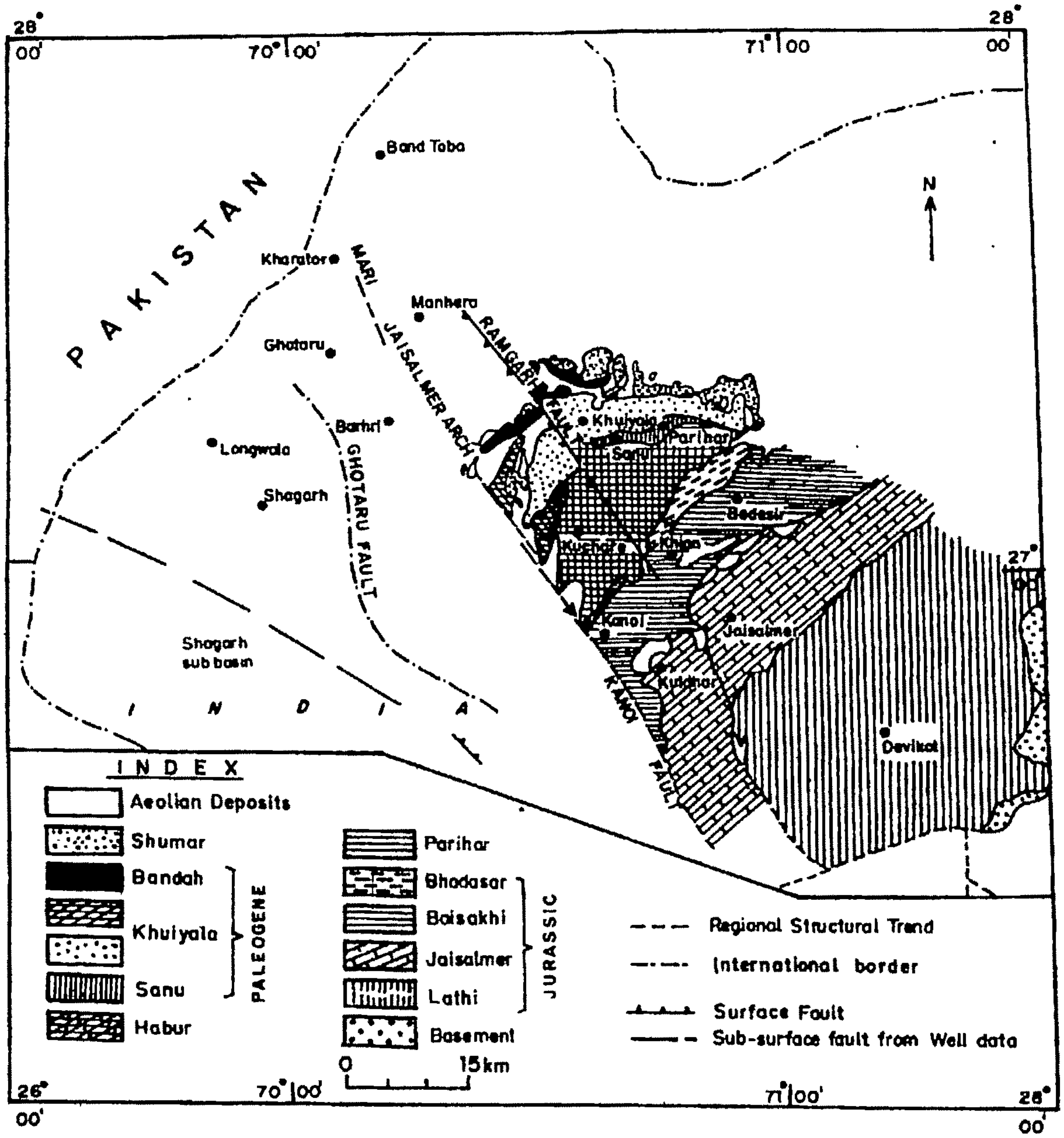

Fig. 1: Location map showing the study area (after Dasgupta 1975)

*Ferricrete profiles*

Generally three types of weathering profiles occur in the Jaisalmer Basin.

Type A: Ferricrete profile with pallid zone and slightly mottled zones capped by ferricrete and cemented by calcrete (site near Bedesir on the way to Sanu, Khian and Mandha)

Type B: Truncated ferricrete profile capped by ferricrete pisolite lag.

Type C: Short profiles (50 cm to 1 m thick) only with a vermicular zone and pisolith.

*Profile description*

Ferricrete profiles as observed at Khian, Mandha near Khian, Bedesir, Khuiyala, Devikot, etc. are presented. The ferricrete profiles have been formed over the sandstone, fossiliferous limestone and flaggy limestone.

Ferricrete occurs distinctly as a capping on the crest of the escarpment of the hill range at Khian and Mandha. The Khian surface is more or less at the same level as Shumar Wali Talai 100 ± 25 m amsl. The litho-section observed at this site reveals a 1 m thick top unit of colluvial deposit rich in iron nodules and pellets cemented by fine powdery

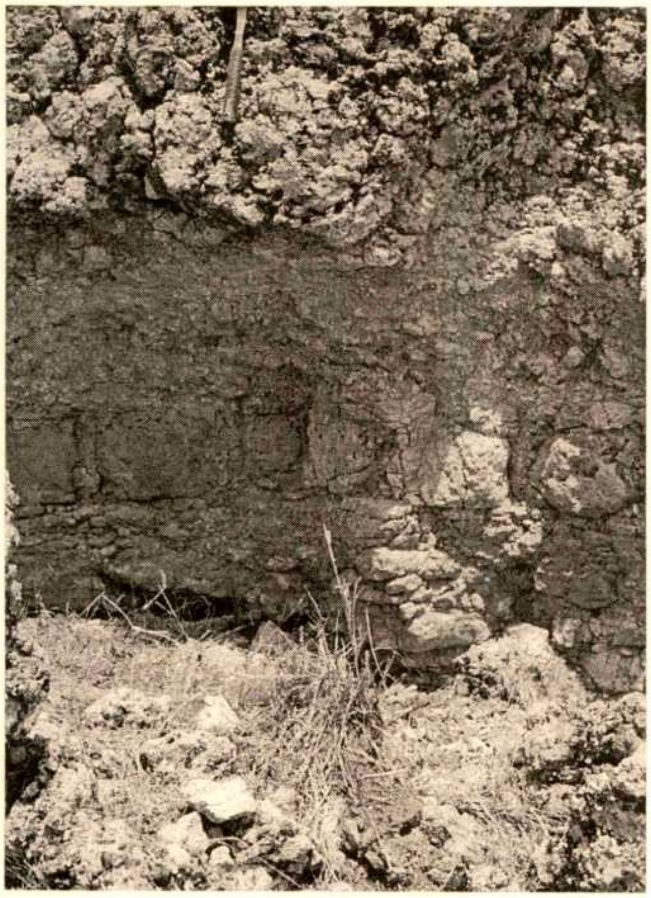

**Fig. 2**: Well exposed ferricrete crust formed over the Khian nummulitic limestone with clays and shale

calcium carbonate which is light brown in colour. Pebble to pebble contact is poor and the matrix is supported by colluvium deposited over a weathered pediment surface of yellowish Jurassic limestone. This yellowish limestone is 1.5 m thick. This unit rests over the nummulitic limestone. This 2.5 m profile has preserved evidence of weathering and karsitic dissolution in the following manner. This litho section represents one of the important regoliths developed over the fossiliferous limestone in the study area. The weathering has not reached the extent of *terra rosa* formation but yet it exhibits solution cavities, karsitic features, blocky weathering, $CaCO_3$ accumulation along the pedal surfaces and the development of yellowish brown gravely soil. This weathered surface represents regolith developed over the pediment. The regolith has been preserved because of the capping of colluvial gravel which covers the vast surface of 1000 $km^2$.

At Mandha the ferricrete crust of 1.8-2 m thickness is formed over a Jurassic period variegated clay unit with a gradational contact. The clay unit (2-2.3 m thick) underlies the ferricrete representing a thick pallid zone. These clay units are also rich in nummulites and alternating grey and pink layers, which are papery and friable with crystals of gypsum/halite. The clay unit is underlain by nummulitic limestone with a sharp contact. The entire profile is only 5 m thick. It was interesting to note that the top surface of the ferricrete crust was vesicular in nature and the vesicles were subsequently filled by $CaCO_3$. Patches of manganocretes of nearly 20-30 cm thickness were exposed on these surfaces.

The manganocretes were largely grain supported with smooth edges. Similar but shallow profiles were observed 3 km towards Deva, about 1.5 km short of Mokal and near Ramgarh. The quarry cutting near Ramgarh revealed a thin veneer of ferricrete nearly 1.50 m thick formed over sandstone with intervening bands of variegated clay and coarse grained ferruginised sediments. Similarly, 31 km short of Sultana en route from Mokal, ferricrete nearly 60-75 cm thick has been formed over variegated clays. The clay unit is highly weathered, papery, splintery and flaky with crystals of gypsum. The sections vary from 3-5 m in thickness.

Near Lavan, 24 km before Pokharan, an exposure of massive ferricrete formed over the ferruginous sandstone was studied. These ferricretes are a typical example of hard pan duricrusts. The pallid zone was difficult to identify in the field because of the high iron oxide content both in the ferricrete as well as in the bedrock. Several patches of bedrock impregnated by iron oxides were observed at Lavan. The thin veneer of ferricrete observed near Ramdeora has been formed over the rhyolites.The Khuiyala Nala section reveals varied types of ferricrete formation over the limestone. The ferricretes are largely slabby in nature and in patches bulbous. The ferricrete surface is overlain by a gravel and boulder spread. A section of the Nala revealed rhizoliths of iron oxide composition (Fig. 3).

Well exposed sections were studied from the excavation carried out for the Indira Nahar Pariyojanaat RD39 near Shumar Wali Talai. The section revealed a metre thick massive bedded ferricrete which grades to a metre thick calcareous coarse grained sediment. The calcareous coarse grained litho-unit reveals a gradational contact with the underlying limestone unit which has intercalations of greyish clay in the top layers and nodular ferricrete in the lower part. Shumar Wali Talai reveals the occurrence of managanocretes formed over the ferricretes of nearly 1 m thickness underlain by limestone with a gradational contact. The manganocretes have a thin (1.5 to 2 mm thick) calcium carbonate coating probably from aerosol dust(?). The Shumar ferricretes occur as a separate surface inset, 5-6 m above the pediplane developed over the Eocene limestone and sandstone formations. RD72 revealed massive vermicular ferricrete with secondary silica infillings in the channels and re-precipitated $CaCO_3$ of the fossils (lamellibranchs and gastropods). This unit grades to

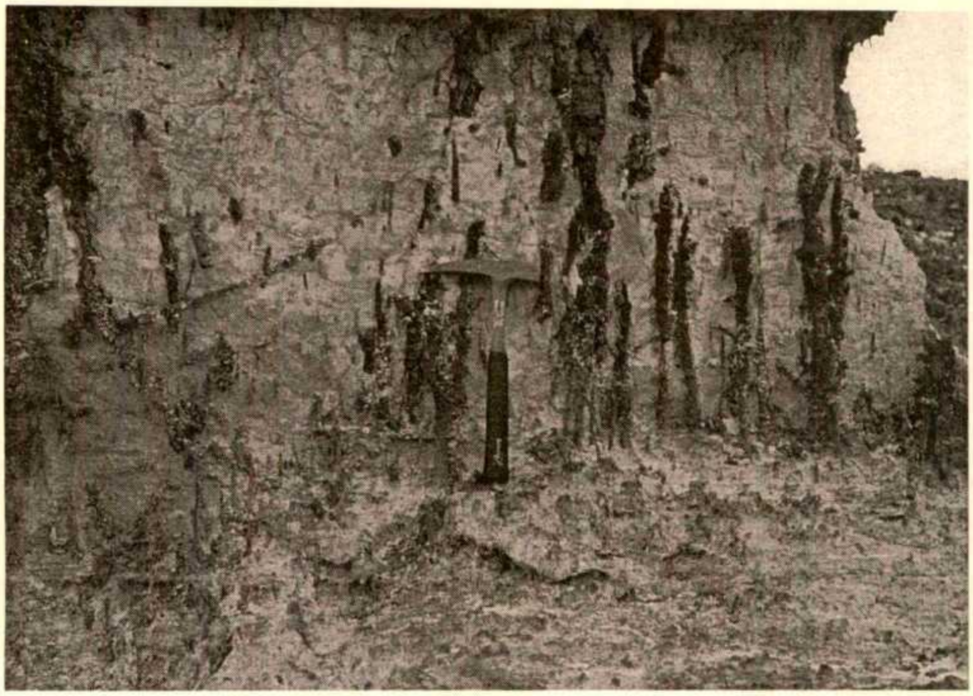

**Fig. 3**: Khuiyala Nala section with Fe-oxide rich rhizoliths

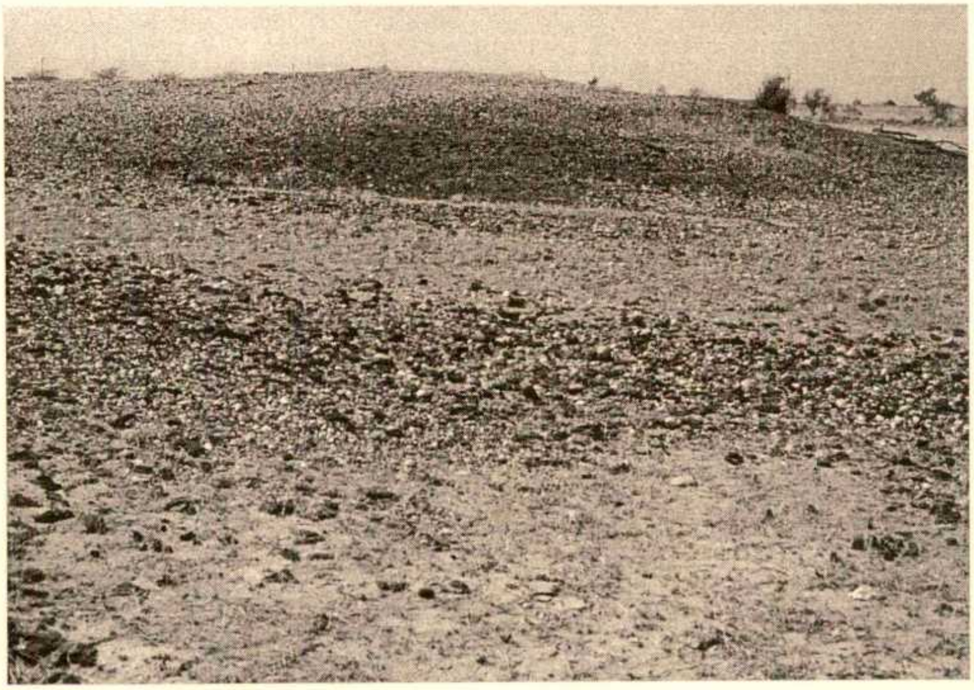

**Fig. 4**: Gravel lag spread of iron oxide rich pisoliths

a partially weathered ferricrete with the intercalation of calcareous and bentonitic clay units. Root traces are common in the calcareous rocks and also in the basal part of the profile, probably indicating subaerial concentration of $Fe_2O_3$ in the ancient landscape.

Lag deposits of ferricrete gravels are observed along Mokal to RD105 of the Indira Nahar Pariyojana and also in patches towards Sultana. These were also observed around Nadai 15 km from Khian.

Manganocretes occur as mantles on hill sides, and below the vesicular zones at Mandha and Khian. They are well exposed as pockets between Shumar Wali Talai, Mokal, Deva, and Boa on the way to Jaisalmer. It is interesting to note that the ferricritised fluvial gravels and manganocrete gravels of Shumar Wali Talai formation (Pleistocene-ONGC stratigraphic date) which are well exposed due to the digging and excavation of the Indira Nahar Pariyojana RD 180, are overlain by a thin veneer of calcretes, colluvial material and dune sediments.

Of all the ferricrete types, pisoliths and nodules constitute significant portions of many ferricrete deposits (Fig. 4). Their relationship to the zones of mottled and bleached bedrock sediment is critical for the understanding of their origin. In sites around Mohangarh, Mokal, and on the way to Sam from Jaisalmer several road cut sections, rills and around Mandha village, pisolitic crust with a clear graded bedding occur.

A large number of pisolites reveal signs of breakage, rehealing and continued growth. The edges are generally very smooth and well rounded. The breakage is probably due to transport during their formation. There are two theories put forward for understanding the origin of pisoliths: a) in situ (Tardy and Nahon 1985), b) transported (Milnes *et al.* 1987; Bourman *et al.* 1987).

Thus ferricretes in the Jaisalmer Basin occur in varied forms and are of varied ages developed on different parent material like those formed on limestone at Sanu, Khuiyala, sandstone at Mandha, fossiliferous sandstone at Khian, Devikot and on the fluvial gravels of Shumar Wali Talai. An individual ferricrete reflects both the character of the original material that has been ferruginized as well as the accumulated effects of subaerial processes. It was vital to understand the types of ferricrete formation and the following methods were adopted.

## Methodology

Samples collected from the ferricrete profiles were analysed for the total elemental concentration. Clay minerals were identified by the XRD method and supplemented by infra-red spectroscopy. Micromorphology of ferricretes (Table 2) were carried out following Bullock *et al.* (1985). In this, inferences drawn are largely based on geochemistry, stratigraphy, geomorphology and micromorphological studies.

Micromorphology and chemical analyses were carried out in detail for the profiles of Khian and Khuiyala in particular as they have been formed on different parent material and they represent an in situ formation of ferricretes in the study area. Thin section and chemical studies were also conducted for sites such as Mandha, Habur, RD 105 and Shumar Wali Talai.

Microfabric elements in polished thin sections provide a basis for the interpretation of processes involved in ferricrete formation. In contrast to the variety of field identified ferricrete types, micromorphological study of thin sections of samples from the area around Jaisalmer Basin indicate only three broad categories of ferricretes: a) ferruginised bedrock (sandstone, fossiliferous limestone, ferruginous limestone), b) Fe-impregnated and indurated sediments including clays, sandy sediments, c) ferricretes of complex sedimentary and pedogenic origin (like the pisoliths). Type a and b ferricretes have simple fabrics and an Fe-oxide mineralogy dominated by hematite and goethite. Mica and feldspar have been variously replaced by Fe-oxides indicating that the environmental conditions are likely to have been arid. In bedrock ferricrete samples it is common to observe the physical disintegration of primary micas due to infiltration of Fe-bearing solutions along cleavages and the subsequent crystallisation of Fe-oxide minerals. Thin section data of the ferricretes (Table 2) suggest multiple phases of iron oxide mobilisation and precipitation within individual ferricretes such as nodular ferricretes, slabby ferricretes and pisoliths.

Magnetite, hematite, ilmenite and goethite are the dominant minerals. All the types of ferricretes have a simple matrix fabric and an Fe-oxide mineralogy represented by hematite and goethite. Iron segregation has produced a great variability of colours, degree of opacification and of forms both external and internal. Colours range from dark red to black, ochreous and brown. Opacification is directly related to the abundance of Fe oxides and also Mn (Federoff 1979). This abundance (G/M+H ratio) was roughly estimated by an optical microscope (Table 2). Voids, channels and fractures exhibit laminated clay deposition of hematite and goethite and some pores are completely filled by limonite or hematite (Fig. 5). These fillings have subsequently imparted an overall reddish colour to certain parts of the thin sections. Some of the channels and fractures are also lined with black manganese oxide representing the final depositional phase. Often the fractures and cracks are partially filled by crystals of gypsum which are secondary in origin.

Colloform structures are commonly observed in the matrix with iron oxide in the intergranular spaces (Fig. 6). Bleached zone material sampled throughout the region

**Table 1**: Micromorphology of ferricretes

| Ferricrete Types | Coarse Fraction Mineralogy | Fine Fraction Mineralogy (XRD Method) | G/M+H | Texture | Features | Remarks |
|---|---|---|---|---|---|---|
| Pisoliths | Quartz, Feldspar, Quartzite, Rutile in traces | Kaolinite, Hematite, Goethite, Magnetite | 3/7 | Independant components with distinct boundaries | Features and cracks coated by multiple and complex rims. | Clastic, later pedogenised |
| Nodular | Quartz, Feldspar, Quartzite, Rutile in traces with Tourmaline and Garnet | Hematite, Goethite, Magnetite, Limonite and Gibbsite | 6/4 | Ooliths and Pisoliths often diffused | Fractures and cracks, colloform structures, >%age of pores and voids between the grains | Some pedogenic and groundwater process |
| Slabby | Quartz, Feldspar, Quartzite, Rutile in traces with Tourmaline and Garnet | Al Hematite, Geothite, Magnetite, Limonite Gibbsite | 4/6 | Platy orientation of $MnO_2$, Fe, FeO separated by Fe clays | Complex mobilisation of clays through channels and voids. | Complex processes |
| Vermiform | Quartz, Feldspar | Al Hematite, Geothite, Magnetite, Limonite Gibbsite and Kaolinite | 5/5-4/6 | Tubules and Channels, filled by Fe rich clays | Complex mobilisation of clays through channels and voids. Presence of mottles. | Complex processes |
| Manganocretes | Quartz, Feldspar | Magnetite and Hematite | 3/7-2/8 |  | Impregnated voids and pore. Fragments also cemented by $MnO_2$ |  |
| Ferricretised Bedrock | Quartz, Feldspar | Hematite, Goethite, Magnetite, Limonite, Gibbsite and Al Geothite | 6/4-5/5 | Bedrock texture and structure preserved. Mottling increases at the base. | Cracks and voids present. >%age of pores increased | Pedogenises |

**Table 2**: Micromorphology of pisoliths

| Nucleus | Composition of the Nucleus in the Pisoliths | | | | |
|---|---|---|---|---|---|
| | **Detrital Matter** | | | **Ferruginous Matter** | |
| Cortex<br>Concentrically arranged and mostly colour banded. Ferricrete material-Magnetite/Hematite | mineral grain | rock fragment | pisoid fragment | homogranular | massive |
| Thick<br>1/2 radius of nucleus | normal or grain pisoid | rock pisoid | two phase pisoid | — | — |
| Thin<br>1/2 radius of nucleus | pisoid to coated grain | rock pisoid to rock fragment | two phase pisoid formation to coated pisoid fragment | nuclear pisoid | compound and nuclear pisoid |
| Absent | (clastic grain) | (rock fragment) | pisoid fragment | ferricrete spheriod | — |

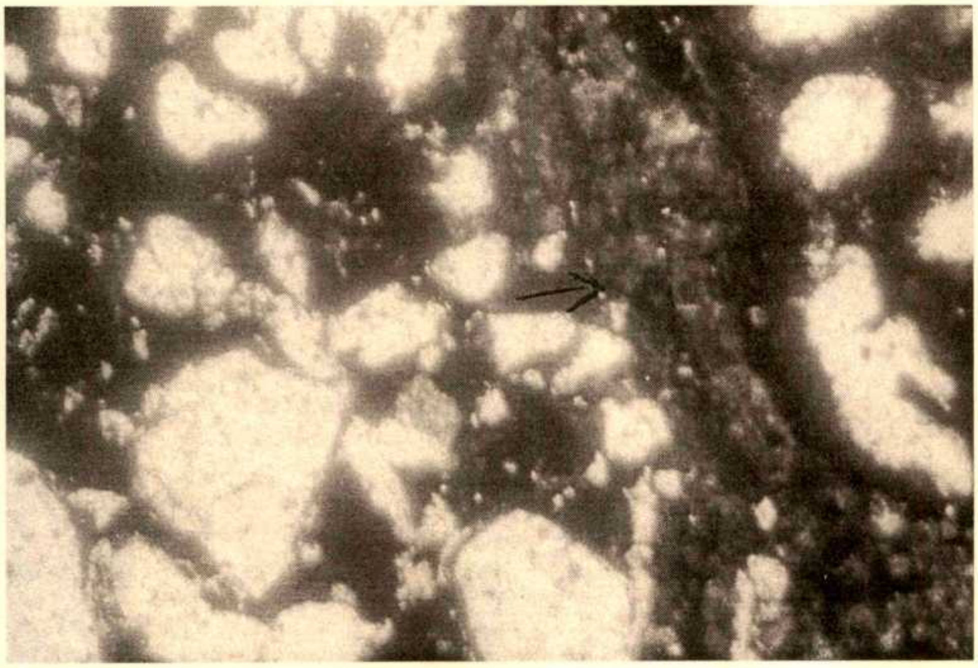

**Fig. 5**: Magnetite/hematite clay deposition in the pores, voids, channels and fractures or around the grains indicate a post depositional phenomenon. x Nicols. x 60 mm

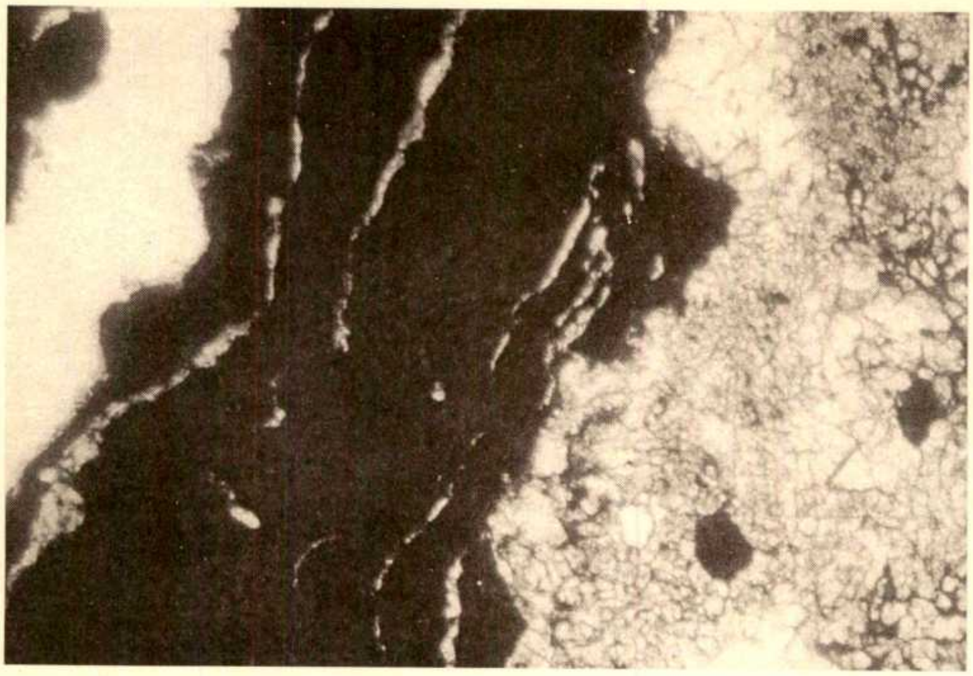

**Fig. 6**: Colloform structure observed within in magnetite pisolith. x Nicols. x 60 mm

contains variable amounts of kaolinite and ubiquitous quartz in addition to mica and feldspars.

Pore size was studied by determining the average pore size diameter 3-6 (mm across) in stained epoxy impregnated thin sections. The pore size decreases with depth. The process of translocation is, therefore, governed by the relative sizes of translocated grains and the diameter and tortuosity of pore structures encountered during the passage through ferricrete/ laterite profiles (Brimhall *et al.* 1988).

Corrosion of primary minerals such as quartz and feldspar (microcline, orthoclase and a few grains of plagioclase) were observed to be intense in the ferricretes formed over the Jurassic sandstone and Cretaceous limestone and sandstone, while the intensity of corrosion in quartz grains is either mild or practically negligible in the ferricretes formed over the Tertiary and Late Neogene/ Early Quaternary sediments. But quartz continues to occur in the younger ferricrete deposits. Corrosion of feldspar has changed from intense during the Cretaceous to weak, during the Late Neogene/Early Quaternary. In addition to the climatic influence, iron enrichment seems to have an intensifying effect on the quartz weathering. The degree of corrosion of primary quartz and feldspars signifies climatically controlled variations.

Micromorphological examinations of thin sections of ferricretes from Mohangarh, Devikot and Bedesir reveal relics of previous ferricretes in the form of angular fragments in the matrix, loose pisolites (40-50 mm) in the samples from the degraded horizons.

On the other hand the mottled or the bleached horizons from Khian, Khuiyala, Mandha, Ramgarh and near Mokal contain kaolinite hematite, goethite, quartz, feldspar and gibbsite. Access for Fe rich solutions appears to have been provided by a network of fractures, cracks and these must have also provided pathways for the removal of alkalis, Si and Al derived from the degradation of the clays.

Type C ferricretes have a complex fabric and a corresponding complex secondary oxide mineralogy including hematite, goethite, magnetite and gibbsite. They are pisoliths containing detrital quartz and are characterised by the presence of ferruginous clasts and pisoliths. The matrix of these ferricretes typically contains limonite, hematite and magnetite, goethite and sometimes gibbsite.

Ferruginous pisoliths in some cases have preserved biogenic signatures in the form of fossil fragments and root pores and channels. The root pores have been subsequently filled partially/fully by Fe oxides (hematite). Pisoliths have a core composed of detrital grains and rinds (2 or 3 complete, sometimes incomplete). The rinds or the laminations are hematite/goethite. The rinds also have the common incorporation of single grains of quartz (60-10 mm) or lenses of grains of quartz between the laminations. In some pisoliths, the pisolith cores are of quartz-rich soil material similar in fabric and composition to the surrounding matrix. They have complex rinds of hematite and

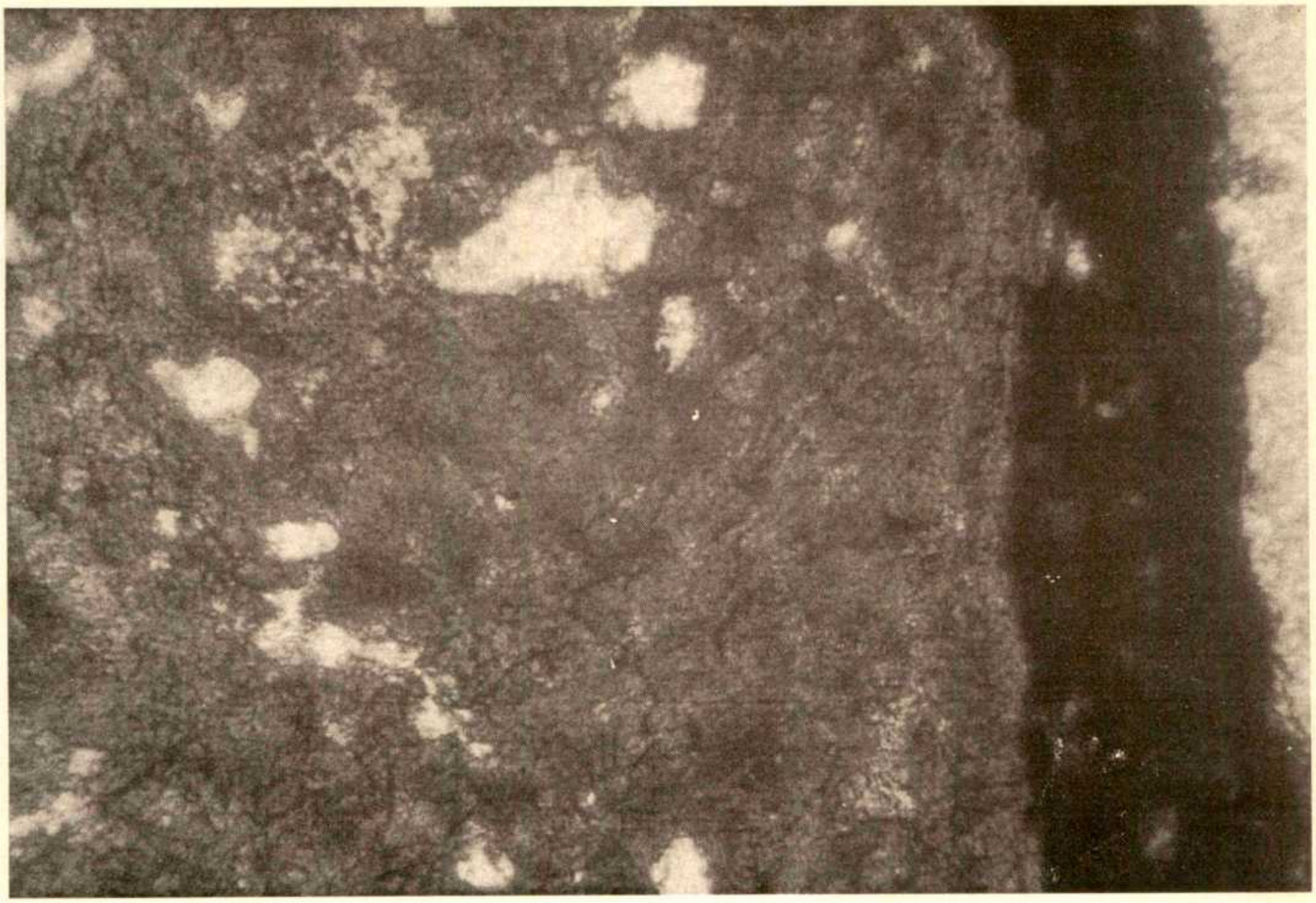

**Fig. 7**: Rind of hematite-goethite around the pisolith. x Nicols. x 60 mm

goethite (Fig. 7). Pisoliths have been derived from the erosion of pre-existing ferricretes and iron mottled zones in the adjacent parts of the landscape. The laminar rinds clearly represent a succession of depositional layers and confirm their accretionary nature. Complex rinds which include goethite and hematite with lenses of quartz grains are signatures of a long history of depositional and accretionary events. These processes could have taken place in a succession of pedogenic environments. Complex pisoliths contain a variety of earlier generations of pisolith structures. This indicates a polygenetic development of ferricrete. Thin section studies of the rhizoliths from Khuiyala reveal Fe impregnation around the siliceous cell structure that are largely distorted with a distinct 3-4 µm size across the root pore. The cortex of the outer layer of rhizolith is well preserved.

Micromorphology of manganocretes reveal quartz rich sediments cemented by magnetite. They consist of quartz rich colluvium probably of the Jurassic-Tertiary sandstone fragments and quartz grains cemented by magnetite. The cement forms an optically opaque plasma around a slightly floating framework of grains. About half the framework grains have displacive fractures filled partially or completely by magnetite or hematite. In some samples there is evidence for a small amount of iron oxide (hematite) cementation prior to the major magnetite cementation.

The iron oxides occurring in all the types of ferricretes are of different colours; red (7. 5R4/6), light yellow orange (7.5 YR 8/6), dark red (7. 5R3/6), dark reddish brown (2.5YR3/4), very dark reddish brown (7.5R2/3) and reddish black (7.5R2/1) corresponding to different mineralogical forms of Fe oxides which can be related to environmental changes. The colour of the ground mass is the only dependable criterion to follow the transformation of iron oxides. Ferruginisation features exhibit signs of disaggradation such as bleaching, i.e. alteration of feldspar and enrichment of kaolinite clay followed by new aggradation such as colloform features as observed in vermiform ferricretes of Indira Nahar Pariyojana (RD 107-110), Gypsum crystals are recycled, blown or incorporated into the ferricretes as a post formation processes.

## Chemistry and Secondary Oxide Mineralogy

The bulk chemical and mineralogical composition of ferricretes and their types exhibit a range of $Fe_2O_3$ concentration with variable $SiO_2$ due to mainly differences in quartz abundance and variable $Al_2O_3$ relating to the amount of gibbsite. Secondary Fe-oxides are hematite and goethite.

Twenty ferricrete samples covering the study area were studied by XRD analyses and the same set of samples were also subjected to infra-red spectroscopic studies. These analyses were conducted at the Centre of Sophisticated Instrumentation and Crystal Growth, Anna University, Chennai to identify the clay minerals. XRD spectra supplemented by infra-red spectroscopy patterns studied, display variable crystallinity of goethite and hematite (as indicated by the broadening of the X-ray diffraction line) indicate a range of Al substitution. The samples that were analysed showed a low degree of Al substitution.

In the present study detailed chemical and micromorphological analyses carried out on ferricretes showed that maghemite occurs with hematite and that they could have been formed by the direct precipitation of $Fe^{2+}$, $Fe^{3+}$ compounds. Maghemite also forms due to bush fires and these are known from the Australian ferricretes (Milnes *et al.* 1987; Bourman 1993b). Bush fires are not known in this part of the study area and thus maghemite could have been directly precipitated by the chemical reaction of iron compounds.

Gibbsite is also one of the mineral constituents of some of the ferricrete types especially the vermiform ferricretes observed near the Indira Nahar Pariyojana RD107-109. The high $SiO_2$ and $Al_2O_3$ values are due to the quartz and rock fragment contents. High concentrations of alumina in ferricretes observed on surfaces exposed to subaerial processes for various periods of time may reflect local bedrock and/or topographic influences that favour leaching rather than indicating severe weathering. Table 3 summarises the geochemistry of the ferricretes.

## Discussion

Based on field data, chemical studies and micromorphology of ferricretes, three broad formations can be recognised: a) pedogenic, those genetically related to weathering profiles; b) ground water; c) combination of a and b which have been transported and deposited in the form of lags.

The close field and topographic relationship between manganocretes and pedogenic duricrust profiles, high MnO (6.4-8.3%) content and their comparatively high $TiO_2$ (1.31-1.56%) content indicate that they represent colluvial mantles and sediments cemented by Mn rich groundwater derived by the weathering of Jurassic-Eocene marine sediments via differential organic complexing as suggested by Cheshire *et al.* (1977). No other obvious source for the Mn is identifiable in the area. The presence of Mn indicates that the ferricrete would have been subjected to water logged conditions, confirming its relict nature. Geochemical analyses of samples between Khian and Khuiala (Table 3) reveal that the ferricrete samples consist mainly of $Al_2O_3$ and $Fe_2O_3$ and have largely been stripped of $SiO_2$, CaO, MgO and $Na_2O$.

Different shades and types of ferricretes indicate varied environmental conditions during their formation, Consequently, detailed characteristics of different ferricretes represent their epigenetic histories. Some of the mobilised Fe has been re-precipitated along the margins of the bleached zones probably in response to oxidising conditions. Ferricretes are produced by accumulation in humid climate from low pH groundwater by evaporation. Low temperatures, higher water activity and reducing conditions favour goethite formation. However, voids containing alternate deposits of laminated hematite and goethite (hematans, goethans) in some ferricretes record fluctuating environmental conditions. Clay mineral studies and chemical data of ferricretes reveal that clay mineral formation has taken place mainly during chemical weathering at a surface environment and in very dilute acidic conditions. Hydration processes involves alternating cycles of hydration and de-hydration (i.e. ferruginisation). This involves the mineralogical change of goethite (a FeOOH) into hematite (a $Fe_2O_3$). Low Al substitution in goethite is characteristic of hydromorphic environments. Fitzpatrick (1987) has summarised data on Fe-oxides and their distribution in soil materials in the southern hemisphere. Goethite is the most abundant and widespread of the pedogenic Fe-oxides, although it commonly coexists with hematite and maghemite (Bourman 1993). The relative concentration of goethite and hematite in pedogenic and weathering environments is strongly influenced by the valence of the Fe source, concentration of Fe in solution and factors such as temperature, moisture activity, pH, Eh, presence of organic matter and the ionic environment including the activity of Al in solution (Schwertmann and Taylor 1987).

Goethite forms from solutions of monomeric $Fe^{3+}$ $FE(OH)^{2+}$ and $FE(OH)^{4-}$ ions through nucleation and crystal growth. Goethite may also form from ferrihydrite via a reconstructive dissolution-reprecipitation reaction . Both maghemite and hematite are known to form readily in pedogenic environments by the heating of goethite during bush fires (Bourman *et al.* 1987). However by laboratory syntheses it has been noted that maghemite may form by direct precipitation of $Fe^{2+}$, $Fe^{3+}$ hydroxy compounds . It is known generally to occur in highly weathered acid soil environments where its formation appears to be dependent on the intensity of leaching under conditions of free drainage. Kaolinite or halloysite are regarded as precursors

**Table 3**: Geochemistry of the ferricretes collected between Khuiyala and Khian

| | **Nadai** | **Shumar Wali Talai** | **Lavan** | **Devikot** | **Kuldhera** | **Mandha** | **Habur** |
|---|---|---|---|---|---|---|---|
| | **pisolith** | **slabby** | **pisolith** | **blocky** | **pisolith** | **blocky** | **pisolith** |
| $SiO_2$ | 42.67 | 63.03 | 46.07 | 61.53 | 45.08 | 38.45 | 41.62 |
| $TiO_2$ | 0.02 | 0.67 | 1.06 | 2.03 | 1.18 | 1.62 | 1.03 |
| $Al_2O_3$ | 9.34 | 6.63 | 4.81 | 7.63 | 9.93 | 5.51 | 4.67 |
| $Fe_2O_3$ | 1.33 | 2.24 | 3.12 | 2.05 | 2.63 | 3.05 | 2.12 |
| $MnO_2$ | 12.35 | 9.45 | 13.61 | 10.65 | 12.08 | 12.80 | 11.55 |
| MgO | 0.06 | 1.05 | 0.09 | 1.35 | 1.25 | 1.55 | 0.95 |
| CaO | 0.03 | 1.45 | 0.05 | 1.40 | 0.06 | 0.02 | 1.30 |
| $Na_2O$ | 0.02 | 0.05 | 0.90 | 1.20 | 0.48 | 0.06 | 0.60 |
| $K_2O$ | 0.06 | 0.03 | 0.04 | 0.02 | 0.04 | 0.05 | 0.06 |
| $P_2O_5$ | 0.07 | 0.08 | 0.06 | 0.08 | 0.12 | 0.03 | 0.13 |

of gibbsite in such environments (Hsu 1997). Physico-chemical weathering in an open system favours greater mobility of alkalis, alkaline earths and Si and promotes segregation of Fe and /or Al (Schellman 1979). Among the new minerals that form thus are the Fe-oxides and the clay group - goethite ($Fe_2O_3$ $H_2O$), hematite ($Fe_2O_3$), kaolinite minerals, gibbsite ($Al_2O_3$ $H_2O$) and quartz.

In the study area the inter pisolith matrix is different in mineralogical composition from that of the pisoliths (Bourman *et al.* 1987) indicating probably different environments for their formation. Ferruginous clay minerals such as gibbsite, hematite, kaolinite, limonite and goethite have been identified in the pisoliths where as the surrounding matrix material is composed of goethite, kaolinite and sometimes magnetite. Pisoliths can be interpreted as a clastic component (Bourman 1993a). But the pisoliths with irregular shapes and diffused laminae indicate an in situ formation. The majority of the pisoliths observed in the study area appear to be transported and reworked such as the lag deposits observed around Devikot, Sam, Sanu, Habur surface, Khuiyala and on the way to Sultana via Ramgarh. Ferricretes are generally associated with ferruginous sandstone (Devikot), rhyolites (near Ramdeora), flaggy limestone (Khuiyala) and fossiliferous limestone (Mandha, Khian). They are also formed over the fluvial sediments as observed around Shumar. The thickness of the ferricrete litho-unit is not more than 1.5-2 m and they are largely massive or slabby in nature. The ferricretes subsequently develop into manganocretes which form a thin veneer of nearly 20-30 cm. Ferricretes have developed a bedded character following the primary sedimentary bedding characters of the original rock. The flat ferricrete surface is an expression of a complex series of erosion, weathering events and its continued change is recorded in the lower levels of the region. The bleached and the iron mottled zones below the top units in the lower region of the Jaisalmer Basin are the pallid and mottled zones. Regolith formation as observed around Khian would have developed close to the groundwater and at/near sea level. Quaternary gullying has exposed 2 cycles of erosional surfaces in this sub basin of Mandha and Khian. The litho sections observed along the Indira Nabar Pariyojana when correlated with the litho-unit observed around Khian, Shumar Wali Talai, Habur, Khuiyala reveals ferricritisation of an ancient pediment surface developed over the limestone and clays and calcareous rocks during the Tertiary-Neogene to Early Quaternary period. Ferricritisation seems to have been formed in a near shore environment. Ferricrete formed over the sandstone, limestone, fluvial sediments, etc. indicate different rates of development at different times, although the basic chemical and environmental niche like near coastal marshy wet bottom landscape would have been the common factor.

### *Ferricretes as palaeoclimatic indicators*

The usefulness of ferricrete and calcrete as morphostratigraphic markers is restricted as it is strongly dependent on whether their formation has been continual or episodic. Difficulties in interpreting climatic influences were demonstrated by Bourman 1993b), who considered that periods of ferricritisation occurred in the Tertiary under warm and probably humid climatic conditions and subsequently during semi-arid to arid conditions, ferricretes were truncated. Evidence of weathering, iron mobilisation and formation, impregnation of $MnO_2/Fe_2O_3$ and ferricrete formation from the Jurassic can be seen in the Jaisalmer Basin, which indicates continual development interrupted by geological events. It is not certain that all types of ferricretes developed under a humid tropical climate (Young *et al.* 1987) nor that development ceased as a result of climatic change. Furthermore, not all ferricrete is fossil regolith/soil, as weathering /pedogenesis is an ongoing transformation taking place over a long period of geological time. In the reconstruction of former ferricrete landscapes, many researchers have assumed former continuity of the present-day isolated occurrences of ferricretes. Discontinuous distribution, however, does not necessarily imply dissection of a former continuous ferricrete. In the study area field data supplemented by borehole lithologs suggests that localised ferricrete deposits developed in favourable geochemical niches. Mulcahy (1960) considered that laterite/ferricrete may not only develop under conditions of low relief but also on valley sides (up to 80° slope) and floors. There are probably optimum topographic conditions for ferricrete formation but the presence of laterite/ferricrete need not imply a former extensive planation surface.

The Tertiary marine sequence in the Jaisalmer Basin, Rajasthan is a south-easterly extension of the Indus Basin, Pakistan. These marine sequences developed in the Jaisalmer region get thicker northwards into Mari, Pakistan (Dasgupta 1975), although subsurface structural features play an important role in the thickness of these sediments. Geomorphologic studies (Fig. 1) and accumulation of sand dunes in the NNW-NW part of the study area indicate that the landscape since the Jurassic period was dominantly erosional in nature. The sand dunes have been formed in a sub basin of the region and are the youngest geomorphologic signatures of the landscape. This is evident from the topographic 210-240 m amsl flat surfaces developed over the limestone and sandstone region between Khuiyala, Devikot, Khian, and Sultanpur which slope towards NNW to NW (8° to 10°). The Mesozoic arm of the sea continued to recede since the Jurassic period with uplift in the landscape probably due to tectonism. The sea never seemed to have transgressed beyond the Jurassic landscape (evident from the bore hole data). The recession and erosion followed the palaeotopographic slope of the region. This activity brought about a certain amount of relief/ elevation to the landscape. The climate of the Cretaceous period was much warmer than at present, perhaps the warmest on a world wide basis than at any other time during the Phanerozoic. The climate was also more equable in that the temperature difference from the poles to the equator was about one-half the present gradient. The ferricrete cover would have been formed either before or immediately after the Upper Gondwana slope was raised above the sea level. It is postulated that this high water table was associated with the Early to Late Tertiary high sea level. Weathering of a landscape of some relief (but low near the shore surface) would have led to considerable lateral variations in the oxidising microenvironmental conditions causing bleaching of iron from some higher parts of the landscape and accumulation in adjacent lower lying areas. Detailed observation of bore hole lithologs indicate that ferricretisation has taken place in phases and that it was not a continuous process. The ferricretes studied seem to be of low level iron rich horizons probably formed at the sea level or subsequently uplifted. Fe accumulated due to chelation process subsequently forming ferricreted sediments, slabby and vesicular ferricretes within the zone of water table fluctuation. Accumulation of Fe oxides is therefore considered to have occurred by vertically and laterally migrating ground water, while induration may have been caused by irreversible drying processes during periods of seasonal water table lowering. Different types of ferricretes have formed at different times in various parts of the same landscape. The ferricretes represent regolith material and sedimentary deposits differentially weathered, impregnated by Fe oxides, $Al_2O_3$ and Mn in response to ground water fluctuations and local environmental changes over various periods of time with some material being inherited from the Jurassic-Tertiary sediments. They have been subsequently modified in phases.

The older Mesozoic rocks were substantially weathered prior to the Mid-Tertiary, probably this occurred when the Indian subcontinent was far below the zero degree equator. Iron for the ferricrete formation was available within the basin itself. There is no long distance source of iron which has been transported for the ferricrete formation. Ferricritisation could have taken place in a humid to sub-humid climate with a rich source of iron in the parent rock and sediments and also with a good internal drainage system. Between the Mid- and Late Tertiary the valley bottom weathered limestone and sandstone were covered by weathered debris including pisolites derived from the valley sides as the valley sides were eroded producing the inverted topography by the Late Neogene when the matrix of the pisolites zone was fixed. Lack of bedding and reworked pisolites in the ferricrete suggests transported debris has not contributed significantly to the ferricrete profile formation. Evidence of intense erosion and mass wasting process implies probably tectonic instability during the period of their formation. There has been a topographic inversion in the northwestern parts of the Jaisalmer Basin since the last phase of marine sedimentation during the Middle Eocene. As surface weathering and mass wasting process, and erosion proceeded, the Fe-oxide mottles may have been progressively exposed at the surface, where they hardened, disintegrated and were transformed partially to goethite and formed lags. No thick residual lag deposit has been formed on steep slopes, but only thin layers of pisolites developed wihin the soils directly overlaying the mottled material. Lag deposition and its formation in these areas reveal physical transport from higher to lower parts of the landscape but over gentler paleoslopes. There may be contribution from residual accumulation (McFarlane 1987) by ferruginous material transported from upslope. Fe concentric bands of varying colour/mineralogy suggest that pisolite growth was either episodic, at least in the immediate vicinity of the pisolith or that the chemistry of groundwater varied through time The manganocretes must have formed as post-landscape inversion probably during the Mid-Late Tertiary period. Their occurrence in the landscape topographically sometimes below the vesicular/mottled zone indicate that the parent rocks continued to weather well into the Late Neogene period. The duricrusts and their spatial relationship demonstrate a complex landscape evolution throughout the Tertiary into the Late Neogene period. The ferricrete gravel bed of Shumar Wali Talai marks the youngest ferricrete phase which could have been deposited in a high energy environment when the sea level as well as the landscape was low by scores of metres during the Early Pleistocene period. Subsequent amelioration in the climate has led to the ferricritisation of the gravel bed and the local deposition of the lag pisoliths. Lag deposition and its formation in these areas reveal several phases of physical transport from relatively higher to lower parts of the landscape. From a genetic view point the occurrence of ferricretes, presently in a semi-arid-arid climate region is a definite indication of palaeoclimatic change. Their occurrence only re-emphasises the view that these land masses had once drifted through warmer latitudes with favourable climatic regimes during the geological past (Bardossy 1973, 1979; Subramanian 1978). As part of the drift of the continents, India also had drifted (2 to 3 cm $yr^{-1}$) from relatively colder southern latitudes (between 37°-57°S) to the present-day monsoon climatic zone. This commenced from about 70 myr (LePichon 1968; Dietz and Holden 1970). With the advent of abundant heat and rain upon entry into this climatic zone, vast areas of Precambrian crustal rocks such as chamockites, granites, gneisses and relatively younger Deccan basalt and sandstone/limestone were subjected to chemical weathering and transformed into ferricretes. The irreversible hardening of the ferricretes has resulted from the stripping of the top soil by down and mass wasting, erosion and lowering of the water table (McFarlane 1987). Warm climates with contrasting wet and dry seasons are known to be most favourable for the formation of iron oxides. Therefore ferricretes from the Jaisalmer Basin can be considered as a climatic indicator of an earlier humid hot phase coupled with factors such as drainage, temperature and organic matter. The formation of ferricretes and their types reveal a complex combination of pedologic, hydrologic relationship covering a long span of geologic time since the Jurassic-Early/Middle Pleistocene period.

## Conclusions

Multi proxy (geomorphology, micromorphology and geochemistry) analyses indicate that the Jaisalmer Basin was subjected to distinct events including deposition and admixture of sandy parent materials, pedogenesis (discolouration of parent deposits by means of hydromorphism), erosion and subsequent hardening into ferricrete due to exposure. Micromorphological studies of the ferricritised component and infilling calcretes exhibit total variation in their mineral content, texture and structural characters. Structures such as different size and shape of ferruginous nodules, degree of opacification of iron oxide, colloform structures size and shape of channels indicate the strong influence of groundwater fluctuations. Mottled and vesicular zones with features such as root pores, cracks and fractures, infilled by iron oxide indicate pedological processes. The ferricretes represent an irreversible, self terminating feature (Yaalon 1971) and is an indicator of palaeoclimatic conditions much wetter than those of today. The occurrence of ferricretes in the Jaisalmer Basin are therefore out of phase with the present climate and thus represents a palaeosol with relict feaures. Ferricretes and their spatial relationships demonstrate a complex landscape evolution throughout the Tertiary-Late Neogene/Quaternary period.

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# Luminescence Chronology of Holocene Sediments from Taipingchuan in the Loess/Desert Transitional Zone, China and its Implications

Zhong-Ping Lai[2], A.K. Singhvi[1], Hui-Zhong Chen[2] and Wei-Jian Zhou[2]

1 Earth Science Division
Physical Research Laboratory
Ahmedabad 380009
India

2 National Laboratory of Loess and Quaternary Geology
Chinese Academy of Sciences
22-2 Xiying Road, Xi'an 710054
China

## Abstract

The loess/desert transitional zone in China is an ideal area to study the timing and amplitude of changes in past climates and associated geomorphic processes. Minor perturbations in atmospheric circulation, viz. changes in the intensity of the winter and summer monsoon, results in regionally extended changes in geomorphic processes. We report here Optically Stimulated Luminescence (OSL) dating, including Green Light Stimulated Luminescence (GLSL) and Infra-red Stimulated Luminescence (IRSL), of loess-desert sections at Taipingchuan as well as a lacustrine sequence at Midiwan which has been dated by radiocarbon and studied for its pollen records on palaeoclimate change. IRSL dating of samples from the Midiwan section show good agreement with calibrated $^{14}C$ dates, and confirm that the horizon can be placed between 11 and < 14 kyr which may correspond to the Younger Dryas event. The present study also brings out several large amplitude arid excursions during the Holocene.

## Introduction

The loess/desert transitional zone in China is an ideal area for palaeoclimate study because of its high sensitivity to seasonal alternations of the East Asian winter and summer monsoons. The winter climate is associated with the dry, cold winter monsoon related to the Mongolian high pressure system, and the summer climate is dominated by the warm, moist summer monsoon marked by the southeasterly air flow from the Pacific Ocean (An *et al.* 1993). The bulk of the rainfall in monsoonal China is characterized by frontal precipitation. The collision of cold continental air with warm, moist oceanic air produces monsoon rains (Wu *et al.* 1994). Variability of monsoon precipitation in eastern Asia at the Pleistocene-Holocene transition is recorded. The transitional zone of sandy desert intermixed with loess is located at the present northwestern margin of the East Asian summer monsoon region, and constitutes a semi-arid desert and semi-humid steppe landscape. Stabilized, semi-stabilized, and active sand dunes, shallow lake basins, and seasonally flowing streams characterise the northwestern part of this zone, while loess-mantled hills and sandy loess platforms (*yuan*) are distributed in the southeastern part of the zone. In winter, the dominant winds are northerly and northwesterly, generating frequent dust storms. In summer, the winds are southeasterly and move inland off the ocean producing about 80% of the annual precipitation in the form of rainstorms. The two sites concerned in this study, Midiwan (MDW) and Taipingchuan (TPC) (Fig. 1), are within the loess/desert transitional zone. In the MDW area, the average annual precipitation reaches 400 mm, and in the TPC area it is 517.9 mm.

Recent studies suggest that the sand-loess-palaeosol sequences within this marginal zone provide a record of high resolution climatic change during the Holocene (Zhou *et al.* 1996), and can be correlated with the SPECMAP record during the last interglacial period (Sun *et al.* 1998). The absence of a numerical chronology has however prevented a detailed interpretation and a stratigraphical correlation with other sequences.

Located near Changlin County in Jilin Province, the Taipingchuan (TPC) sections are sand dune deposits, comprising sand and interstratified palaeosols. The sections are exposed by water erosion. TPC1 section (44°21.3' N, 123°14.5'E) is 12 m thick, and TPC2 section (44°16.9'N, 123°16.7'E) is 7.5 m thick. The Midiwan (MDW) section (37°39'N, 108°37'E), which exposes 13.8 m of sediment and has been dated by radiocarbon (Zhou *et al.* 1996), is located on the first terrace of the Xuanhe, a seasonal tributary of the Heiheze River, a second-order tributary of the Huang He (Yellow River).

## Luminescence Dating Method

Luminescence dating is based on the premise that the minerals comprising the sediments are exposed to light

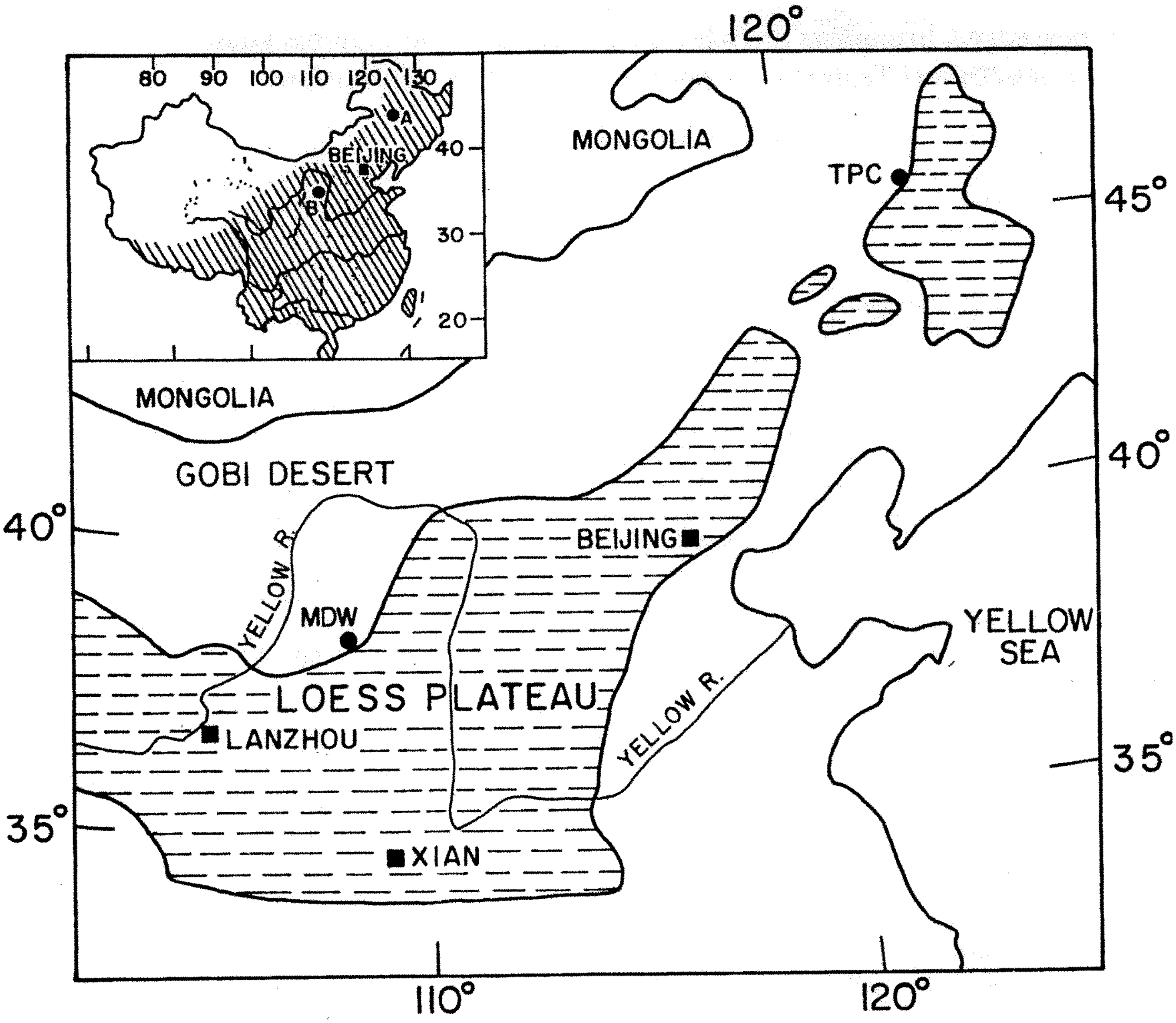

**Fig. 1**: Study area of loess and desert transitional zone in China. To the north of the loess plateau is the Gobi desert. The inset shows the location of the study sites. Site A is TPC (Taipingchuan) and site B is MDW (Midiwan). The shaded area in China is influenced by the summer monsoon (Gao *et al.* 1962)

during their pre-depositional weathering and/or transportation. This daylight exposure reduces the geological luminescence to a zero/negligible residual value. Further exposure to light ceases after burial and a re-accumulation of the luminescence signal occurs due to radiation exposure from radiation arising from the decay of natural radioactivity *viz.* $^{231}$U and $^{232}$Th and $^{40}$K, along with cosmic rays. This signal re-accumulation continues unabated till the excavation of the sample. Large mean lives of these radionuclides imply that the radiation flux is almost constant over time scales of millions of years. Thus, the age of burial can be estimated using a simple equation:

Age = Luminescence acquired since burial/annual rate of luminescence acquisition

In practice however, the equation is more complex since the radiation flux comprises alpha particles, beta, gamma and cosmic rays, and the efficiency of luminescence production is different for alpha as compared to beta, gamma and cosmic rays. A more general version of the equation is:

$$\mathrm{Age} = \mathrm{Pl}(aD_\alpha + O_\beta + D_\gamma + O_c)$$

Where *a* is a sample dependent alpha efficiency factor, and P is the palaeodose implying the laboratory dose that would induce luminescence identical to that in a natural sample. Values of D are component dose rates arising from each of the radiation types. Thus a dating experiment needs two types of measurements, viz. a luminescence measurement to estimate the palaeodose P and a radioactivity assay to obtain the annual dose D.

For aeolian deposits it is reasonably established that the OSL clock is reset to near zero residual value at the time of deposition. Experiments by Huntley *et al.* (1985) have demonstrated that the OSL signal can be reduced to < 10% level with daylight exposure of a few tens of seconds. The daylight bleaching rate depends on the mode of transport (aeolian and fluvial), the sediment load, the duration of daylight exposure as also the mineral type. It is generally seen that quartz GLSL bleaches more rapidly than feldspar IRSL. Thus a comparative dating study on two different mineral types (quartz and feldspar) from the same sample can be instructive as to the extent of bleaching, and therefore in ascertaining the reliability of ages. With this in view GLSL ages on quartz and IRSL ages on K-feldspar were measured.

### Sample Preparation

Mineral separates (quartz and K-feldspar) were extracted after pretreating the samples with 1 N HCL (to remove carbonates), 30% $H_20_2$ (to remove organic debris), followed by magnetic separation and sieving. Typically a 125-150 μm grain fraction was used for TPC samples, and a 90-125 μm for MDW samples. Na-polytungstate heavy liquid separation was then carried out ($p = 2.58$ g/cm$^3$) to separate quartz and feldspar fractions. The quartz fraction was then treated with 40% HF for 80 minutes to remove the residual feldspars along with the alpha skin. No etching of K-feldspar fraction was attempted in view of the possibility of non-uniform etching. The purity of the quartz was examined by IRSL stimulation (Short and Huntley 1992).

### Measurement Techniques

GLSL stimulation was achieved using a tungsten-halogen lamp filtered to restrict wavelength from 420 to 550 nm. IRSL stimulation was done using TEMP IR diodes with stimulation of 880 ± 80 nm. The detection optics comprised Schott U-340 + BG-39 and HA-3 filters (GLSL), and a combination of Schott BG-39 and Corning 7-59 (IRSL) filters coupled to an EMI 9635QA photomultiplier tube. The IRSL measurements of the MDW samples were made on a Daybreak 1150 TL/OSL Reader. The GLSL and IRSL r-measurements of the TPC samples were made using the Riso TL/OSL-DA-15 system. A $^{90}$Sr/$^{90}$Y-beta source, was used for the beta irradiation.

For radiation dose measurements, the potassium content was determined using a flame photometer for the MDW samples, and a NaI scintillation γ-spectrometer for the TPC samples. The U and Th contents were determined by means of neutron activation analysis for the MDW samples, and by a thick source Alpha Counter for the TPC samples. The internal beta radiation was estimated from an assumed potassium content of 12.5 ± 0.5% (Huntley and Baril 1998). The cosmic dose was estimated as 150 Gy/a (Prescott and Hutton 1988). The ages were calculated using the age programme supplied along with the Riso TL/OSL Reader with an assumed water content of 10 ± 5% for the TPC samples and of 15 ± 5% for the MDW samples.

All the long-shines were made at 30° C for 60 sec immediately after preheating for 300 sec at 220° C for the MDW samples and 60 sec at 220° C for the TPC samples. The additive dose method (Singhvi *et al.* 1982) was used to get the palaeodose (P), and the growth curve was plotted after short-shine normalization using linear or saturating exponential fitting. A good shine plateau was seen in the IRSL, but in the GLSL a good shine plateau could be seen only after late-light subtraction (Aitken and Xie 1992). Thermal transfer correction (Huntley *et al.* 1993) on sample $CHN_3$ both for IRSL and GLSL was found to be negligible (Lai and Singhvi1998).

### Results and Discussion

Table 1 provides the palaeodose and radioactivity data and the luminescence ages. Figure 2 and 3 provide a comparison between the radiocarbon and IRSL ages and between the GLSL and IRSL ages. The comparison between radiocarbon ages and IRSL ages is made assuming that the materials dated using radiocarbon are autochthonous and do not involve any correction due to a finite reservoir age and post-depositional contamination. In view of the fear that quartz and feldspar bleach differently on daylight exposure the overall concordance between IRSL ages and GLSL ages points to a complete bleaching of sediments. Figure 4 summarizes the stratigraphy and the chronological

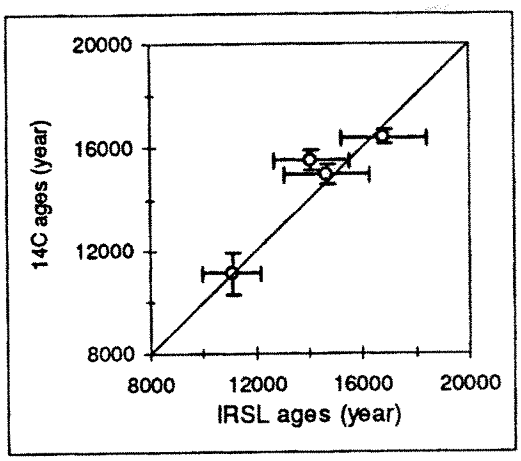

**Fig. 2**: Comparison between IRSL and $^{14}$C ages of the Midiwan section

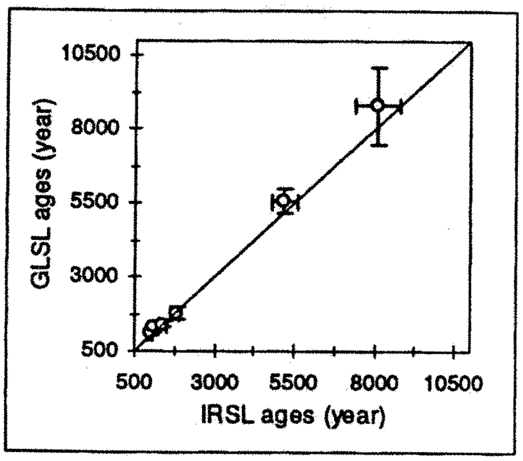

**Fig. 3**: Comparison between IRSL and GLSL ages of the Taipingchuan sections. A good agreement is seen although the IRSL ages tend to be slightly younger than the GLSL ages

data. In the MDW section, Zhou *et al.* (1996) identified the presence of the Younger Dryas event. Radiocarbon ages of 10.3-11.96 kyr at 8.35 m and 14.6-15.4 kyr at ±1.43 m compare well with the IRSL age of 11. 1 ± 1.1 kyr at 8.4 m and 14.7 ± 1.6 kyr at 11.60 m (Fig. 4). The IRSL dating therefore provides confirmation of identification of the Younger Dryas event, which is also seen to the west of the loess plateau (An *et al.* 1993). Though the IRSL ages and GLSL ages concur well within error limits, in general IRSL ages appear marginally lower, as indicated by a slope of 1.088 in Figure 3. This may be a consequence of age-underestimation of IRSL ages with a mean "decay-time" of -70 kyr.

The sequences TPC1, TPC2 and MDW reflect several phases of climatic variation (Fig. 4). In the TPC sections, the sediments vary from desert sand to silt and palaeosols, and from peat to sand for MDW. Conventionally these changes have been interpreted as reflecting changes in the relative intensity of the East Asian monsoon and winter monsoon systems.

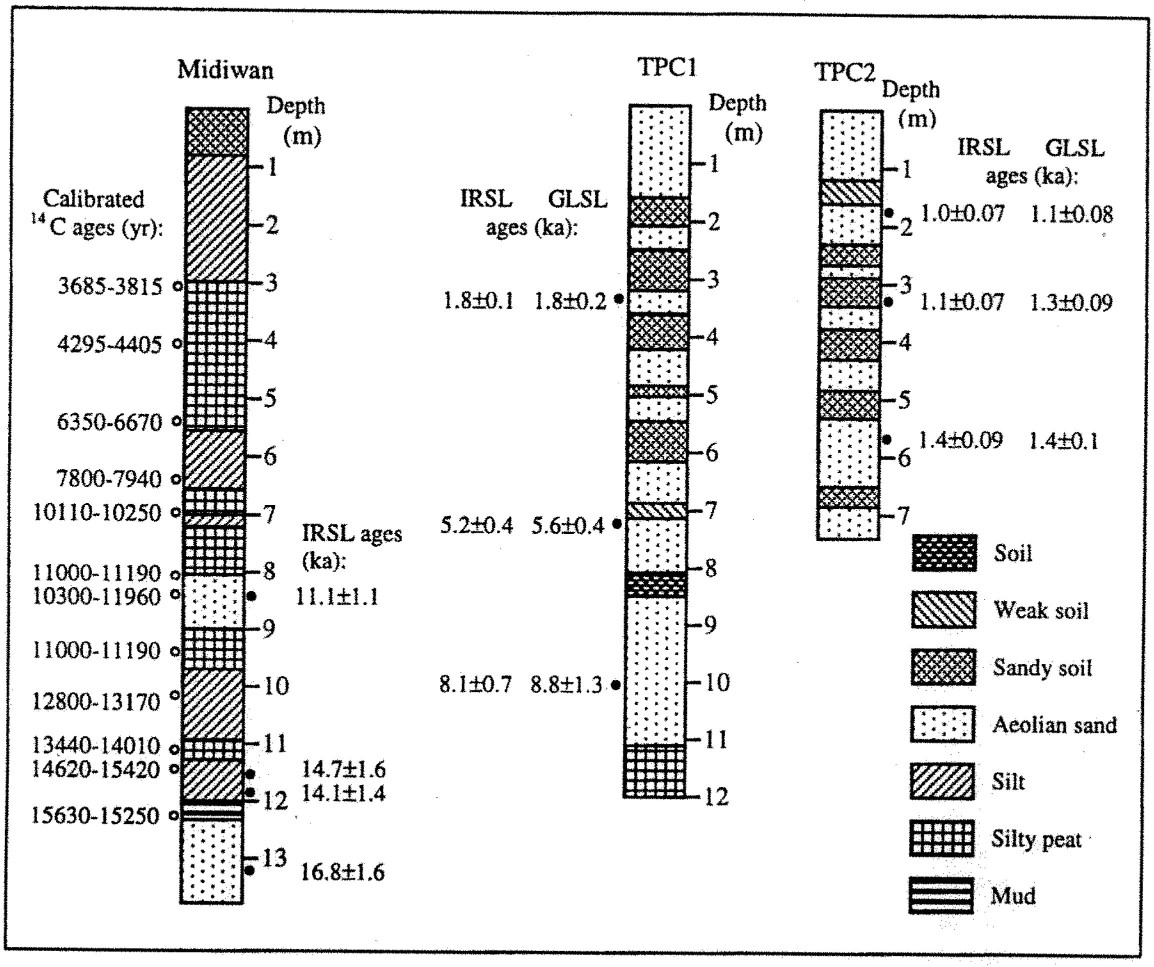

**Fig. 4**: The profiles in this study showing OSL dating results along with existing $^{14}C$ ages (Zhou *et al.* 1996)

**Table 1**: Radioactivity and OSL dating results

| Sample | Lab No. | Depth (m) | U (ppm) | Th (ppm) | K (%) | Water Content (%) | Cosmic Dose (μGy/a) | Total Dose Rate (Gy/ka) | ED (Gy) | Age (ka) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **IRSL**: (F-K*) | | | | | | | | | |
| MDW4 | MDW4 | 8.4 | 1.35±0.24 | 4.39±0.53 | 1.39±0.20 | 15±5 | 150±30 | 2.49±0.24 | 27.6±1.1 | 11.1±1.1 |
| MDW7 | MDW7 | 11.6 | 3.23±0.40 | 4.23±0.56 | 1.73±0.20 | 15±5 | 150±30 | 3.36±0.30 | 49.6±0.34 | 14.7±1.6 |
| MDW8 | MDW8 | 11.9 | 2.77±0.30 | 4.71±0.53 | 1.51±0.20 | 15±5 | 150±30 | 3.05±0.27 | 43.0±2.30 | 14.1±1.4 |
| MDW9 | MDW9 | 13.25 | 1.52±0.20 | 5.12±0.60 | 1.67±0.1 | 15±5 | 150±30 | 2.85±0.21 | 48.0±3.20 | 16.8±1.6 |
| TPC2-1 | CHN1F | 1.8 | 1.22±0.24 | 3.08±0.84 | 2.5±0.1 | 10±5 | 150±30 | 3.17±0.21 | 3.3±0.09 | 1.0±0.07 |
| TPC2-2 | CHN2F | 3.2 | 3.17±0.78 | 1.03±0.22 | 2.5±0.1 | 10±5 | 150±30 | 3.39±0.26 | 3.8±0.10 | 1.1±0.07 |
| TPC2-3 | CHN3F | 5.65 | 1.78±0.34 | 3.65±1.18 | 2/8±0.1 | 10±5 | 150±30 | 3.61±0.24 | 5.0±0.16 | 1.4±0.09 |
| TPC1-3 | CHN4F | 10 | 0.33±0.37 | 7/54±1.28 | 2/5±0.1 | 10±5 | 150±30 | 3.30±0.23 | 26.6±1.30 | 8.1±0.7 |
| TPC1-1 | CHN5F | 3.2 | 1.20±0.18 | 2.04±0.64 | 2.4±0.1 | 10±5 | 150±30 | 3.03±0.20 | 5.4±0.08 | 1.8±0.1 |
| TPC1-2 | CJM6F | 7.15 | 1.09±0.24 | 3.35±0.83 | 1.9±0.1 | 10±5 | 150±30 | 2.62±0.18 | 13.6±0.33 | 5.2±0.4 |
| | **GLSL**: Quartz | | | | | | | | | |
| TPC2-1 | CHN1Q | 1.8 | 1.22±0.24 | 3.08±0.84 | 2.5±0.1 | 10±5 | 150±30 | 2.66±0.21 | 3.0±0.13 | 1.1±0.08 |
| TPC2-2 | CHN2Q | 3.2 | 3.17±0.78 | 1.03±0.22 | 2.5±0.1 | 10±5 | 150±30 | 2.89±0.26 | 3.9±0.31 | 1.3±0.09 |
| TPC2-3 | CHN3Q | 5.65 | 1.78±0.34 | 3.65±1.18 | 2.8±0.1 | 10±5 | 150±30 | 3.06±0.24 | 4.4±0.18 | 1.4±0.1 |
| TPC1-3 | CHN4Q | 10 | 0.33±0.37 | 7.54±1.28 | 2.5±0.1 | 10±5 | 150±30 | 2.79±0.23 | 24.5±3.40 | 8.8±1.3 |
| TPC1-1 | CHN5Q | 3.2 | 1.20±0.18 | 2/04±0.64 | 2.4±0.1 | 10±5 | 150±30 | 2.44±0.19 | 4.4±0.27 | 1.8±0.2 |
| TPC1-2 | CHN6Q | 7.15 | 1.09±0.24 | 3.35±0.83 | 1.9±0.1 | 10±5 | 150±30 | 2.12±0.18 | 11.9±0.30 | 5.6±0.4 |

* Potassium-rich feldspar was not etched by HF, alpha efficiency is taken as 0.2

The peat layer dated at 8.1 kyr at TPC reflects a warm and humid (strengthened summer monsoon) period during which vegetation was well developed. In the MDW section, a silty peat was also developed between c. 10.1-7.9 kyr. Daihai Lake (40"30' N, 112"40' E) in Inner Mongolia in China, which is between MDW and TPC within the marginal zone, shows a high level at the beginning of the Holocene (Zhou *et al.* 1 991). The Qinghai lake (36"30'-37"12' N, 99"36'-100"38' E) had a low level until 7 kyr (Shi *et al.* 1989). This suggests that the strengthened monsoon circulation already dominated the TPC and MDW areas by 7 kyr but had much a weaker influence on the Qinghai Lake area, which was much further inland.

Between 8.1-4.0 kyr, the TPC site experienced about 4 cycles of loess-sand-soil alterations with a well-developed soil layer between the depth of 8.1 and 8.6 m (~6.5 kyr) which suggests a warm and humid climatic period. Between 8.1 m and 7.2 m (~6.0-5.2 kyr), aeolian sand suggests a return to aridity. Interestingly, this return to aridity is also reported from the Bangong Co basin in western Tibet between 6.2 kyr and 5.7 kyr (Gasse *et al.* 1996). Climatic fluctuations are also seen in the Daihai Lake record which showed a short period of low levels between high levels during this period (Zhou *et al.* 1991). The deposits in MDW varied from silt (until about 7 kyr) to silty peat (7-4 kyr) suggesting a warm and humid climatic period which was also seen in Qinghai Lake (7-4 kyr) (Shi *et al.* 1989). The above records suggest a general warm and humid climate during the mid-Holocene, matched by a high lake stand of 30-35 m above the present level at Issyk-Kul Lake near Alma Ata 6-4 kyr (Pomorzev 1988). These indicate a marked strengthening of the monsoonal circulation at this time with deep penetration into central Asia.

Since 4 kyr there have been 4 palaeosol layers in TPC1 and at least 5 palaeosol layers in TPC2 reflecting frequent climatic fluctuations, especially during the last 1.4 kyr. Similar fluctuations were seen in Bangong Co basin with a dry episode between 3.8-3.2 kyr, a wet episode of minor amplitude between 3.2-2.1 kyr, a wet interval between 2.1-1.3 kyr, and at least 3 phases during the last 1.3 kyr (Gasse *et al.* 1996). The $\delta O^{18}$ record of the Dunde ice cap to the west of Qinghai Lake indicates that, during the last 5 kyr the warmest period occurred between 3.5 kyr and 2.9 kyr, and it has been clearly colder in the Qinghai region since the last 3 kyr with the coldest climate occurring around 1000 A.D. (Zhou *et al.* 1991).

## Conclusions

The present study offers several interesting and important conclusions that strengthen the overall palaeoclimatic reconstruction for the region.

- A good agreement between the IRSL and GLSL dates and calibrated $^{14}C$ dates demonstrates that luminescence dating is applicable to the lacustrine sediments of the region. The basic advantage of luminescence dating is that it offers a means of directly dating the sediments. This is an improvement over radiocarbon where it is not always easy to establish the relationship between the age of the sample and age of its context. IRSL results confirm that the layer dated between 11 and < 14 kyr in this area corresponds to the Younger Dryas episode.
- The overall concordance between IRSL and GLSL indicates complete bleaching.
- The luminescence ages suggest that the sediments at TPC reflect greater climatic fluctuations compared to those at MDW and therefore they have a higher sensitivity to monsoonal climatic change. This suggests a shorter response time for sedimentation processes on the land as compared to the hydrological changes in the lake system.
- The chronology of TPC demonstrates that the period before 8.1 kyr witnessed a warming trend following the end of the last glaciation. A short period of warm climate is seen at 6.5 kyr, after which there was a return to aridity between about 6 and 5.2 kyr. The climate was extremely unstable showing frequent fluctuations during the last 1.4 kyr.

Further studies on the records of palaeoclimatic change, such as pollen concentration and organic carbon in the TPC area will certainly cast light on the understanding of East Asian monsoon climatic and environment changes. The revival of the Milankovitch astronomical theory of ice ages (Berger 1977; Imbrie and Imbrie 1979) can explain the climatic fluctuations on time-scales of 10,000 years and longer. However, short time-scale fluctuations within the Holocene still demand answers. The present study however makes it clear that the Holocene period has also witnessed large amplitude changes in climate-driven geomorphic processes.

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# Radiolarian Monsoonal Index *Pyloniid* Group Responds to Astronomical Forcing in the Last ~500,000 Years: Evidence from the Central Indian Ocean

Shyam M. Gupta

National Institute of Oceanography
Dona Paula
Goa 403 004
India

## Abstract

Pyloniid radiolarians, oceanic micro-zooplanktons (surface water dwelling), are sensitive to monsoon sea surface temperature and salinity, and their variation down a core may provide an insight into the proxy climatic changes in the tropical Indian Ocean. In the present study, the Pyloniid's percentage distribution at ~5 kyr intervals during the last ~500 kyr (± 10 kyr) years exhibited sinusoidal changes in a biostratigraphically dated sediment core (AAS-2/3; 7.49° S, 80.01° E, water depth ~5463 m) from the central tropical Indian Ocean. Characteristics of Pyloniid variation in time suggest several short and long term periodic changes in the proxy monsoonal record. Fourier Transform Spectral Analysis of Pyloniid percentages revealed the triplet peaks of the earth's orbital cycles at the eccentricity (405-, 129- and 95-kyr), obliquity (41- and 30-kyr) and precessional (23-, 19- and 17-kyr) bands. The results suggest that the Pyloniid group of radiolarians, a proxy index for the southwest monsoon, exhibit cyclic changes at the earth's orbital precession, obliquity and eccentricity cycles in the last 500 kyr.

## Introduction

The southwest monsoon is the backbone of the Indian economy and its failure (drought) or excess (flood) affects the common man in many ways. Palaeomonsoon studies provide a database for studying the response-mechanism of natural forces governing monsoon dynamics in the geological past. Historical accounts in India provide evidence that the boundaries of theThar Desert have been shifting. Megasthanes (~300 B.C.) wrote that northwest India was thickly vegetated during the Mauryan period, and that during the invasions of Alexander (~326 B.C.) and Mahmud Gazni (~1100 A.D.) Sindh and Rajasthan were both well vegetated and supported agriculture (in Pant and Rupakumar 1997). Similarly during the Late Pleistocene/ Holocene period Rajasthan had better rainfall and vegetation than at present (Singh *et al.* 1974). However, climatic changes, for the twenty-first century in the report of the Inter-Governmental Panel on Climate Change (IPCC 1995: phase-II) are alarming. It is projected that if the current trend in temperature rise continues, the effects on climate would be drastic in the next century. An estimated rise of about ~1-3.5° C in temperature may change the atmospheric circulation pattern resulting in changes in the evaporation-precipitation balance (E-P) that may cause ecological shifts in the vegetation, forests and agriculture. Additionally, monsoonl rainfall on the Indian subcontinent may be excessive in the next century, because an enhanced inter-annual variability of mean monsoon precipitation over South Asia is found to be associated with greenhouse global warming (Meehl and Washington 1993).

Such projections for the next century warrant retrospection on the subject of past climate to provide background information on natural forces, such as incoming solar radiation (insolation) affected by the earth's orbital forcing and ocean-atmosphere coupling, to identify interferences from the anthropogenic effect on climatic-dynamics. On the geological timescale, climatic models suggest that the earth's orbital eccentricity affects solar insolation related temperature change to the order of ~0.5° C (Crowley and North 1991: 136). The resulting atmospheric circulation and precipitation changes could thus lower oceanic salinity. The modern summer SSTs (sea surface temperature) of the tropical Indian Ocean are positively related to the cloudiness-index (r 0.56, Gadgil *et al.* 1984) and monsoon rainfall (r 0.55, Nicholls 1995). Recently, Gupta *et al.* (1996) found that the tropical Indian Ocean SSTs, reconstructed by radiolarian transfer functions, have oscillated between 26-29° C while the threshold for the super greenhouse effect is ~27° C (Ramanathan and Collin 1991). Similarly, radiolarian palaeo-factors in the sediment core SK-69/1 suggest monsoon oscillation of the 10° S hydrographic front, south of Sri Lanka, during the last 1.4 million years (Gupta and Fernandes 1997). Therefore, the use of empirical relationships between

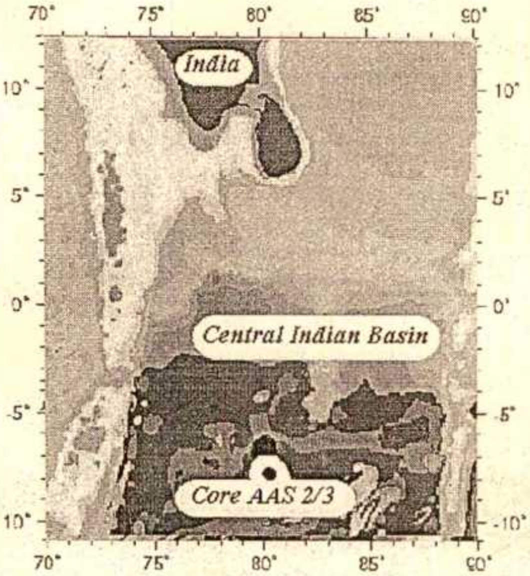
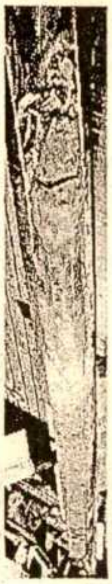
| Location of the core AAS 2/3 | AAS 2/3 | cm | Age |
|---|---|---|---|
|  70°<br>75°<br>80°<br>85°<br>90°<br>10°<br>5°<br>0°<br>-5°<br>-10°<br>India<br>Central Indian Basin<br>Core AAS 2/3 |  | -0 cm | |
| | | -185 | ~ -180 ka<br>FAD of<br>*B. invaginata* |
| | | -435 | ~ -425 ka<br>LAD of<br>*S.universus* |

**Fig. 1**: Location of the core AAS 2/3 in the central Indian Ocean Basin and its coloured and laminated lithology

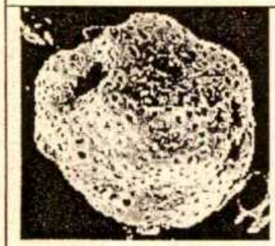
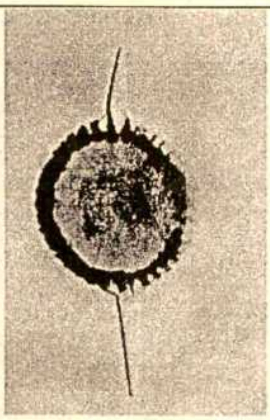
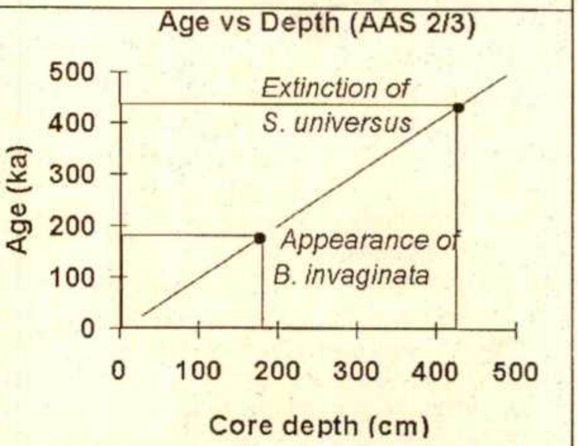
| ***B. invaginata***<br>**X 300** | ***S. universus***<br>**X 160** | **Age versus core depth plot**<br>**Sedimentation Rate : 0.95 cm / 1,000 years** |
|---|---|---|
|  |  |  |

**Fig. 2**: Age versus core depth plot for the sedimentation rate (~0.95 cm/1,000 years) in core AAS 2/3 along with radiolarian datum levels used for the biostratigraphic ages

radiolaria and salinity, SSTs and solar insolation are a prerequisite for the synthesis of monsoon dynamics in the geological past.

The monsoon rains lower the surface salinity (< 34.5 ppt) due to a negative balance between evaporation-precipitation (-E-P) towards the Bay of Bengal, while surface water remains highly saline (> 34.5 ppt) due to a positive balance (+E-P) towards the Arabian Sea. These two salinity extremes are separated by an oblique boundary along the 34.5 ppt isohaline (Gupta 1996: fig. 1d) situated south of Sri Lanka (Wyrtki 1971) due to monsoon precipitation and the the enormous amount of freshwater runoff from the Indian rivers (i.e. Ganga, Brahmaputra, Mahanadi, Kaveri, Krishna). Because the majority of radiolaria inhabit the top 100 m of oceanic water (Anderson 1983), they potentially record changes in surface salinity and SST. Therefore, radiolarian groups (Gupta 1991, 1996) are used to study monsoon salinity and SST (Gupta and Fernandes 1995) changes in the tropical Indian Ocean. A coarser interval (~40 ka) study of the radiolarian palaeo-factors in a sediment core (SK-69/1) revealed cyclic monsoon oscillation of the 10° south hydrographic front (south of Sri Lanka) during the last 1.4 million years (Gupta and Fernandes 1997). These encouraging results prompted the author to initiate a high resolution (~5 kyr interval) study for the last 500 kyr years. The results are presented in this paper.

## Material and Methods

Basic information on the modern distribution of radiolarians in surface sediments and their relationship with the overlying SSTs, salinity, and productivity of the central tropical Indian Ocean is described in Gupta (1996) and Gupta and Fernandes (1997). A well-preserved climatic record is found in a sediment core (AAS-2/3) collected from the central Indian Ocean Basin (7.49° S; 80.01° E; water depth ~5463 m; core length 512 cm) during a cruise by the R.V. Alexander Academia Siderenko (Galenzick, Russia), organised by the National Institute of Oceanography, Goa (Fig. 1). Core AAS 2/3 exhibts pale-brown, laminated (~1 cm) sediments and it was sub-sampled in 1 cm thick slices at intervals of 5 cm for the core length (510 cm). A total of 103 samples were dried, weighed, dispersed in sodium hexa-meta phosphate, hydrogen peroxide and sieved through a 62 micron mesh. The coarse fraction consisted of well preserved radiolarian ooze. A small aliquot from each yield was taken to prepare two permanent slides from each sample (2 x 103 = 206 slides) in Canada Balsam. Radiolarian preservation and abundance were recorded from all the samples and biostratigraphy was worked out for the core. Twenty-five radiolarian groups which qualified for the >2% abundance criteria, (Gupta and Fernandes 1997) from the original 47 groups (Gupta 1996) were also quantified. The earth's orbital eccentricity, axial tilt (obliquity), precession of equinoxes and the incoming solar radiation (on 1st August) at the core site (latitude 8° S) for the last 500 kyr years was computed by the astronomical formulae of Berger (1994) and Berger and Loutre (1991) using Analyseries software (Paillard *et al.* 1996). The percentage of all the 25 radiolarian groups was plotted in a time series and analysed for response mechanism by spectral analysis with Welch window, Ofac -16, Hifac -1, segment 2, 50% overlap, detrended, bandwidth 0.003, significance level 99% setting using the programme of Schulz and Stattegger (1997). Variations in all the 25 radiolarian groups for the 500 kyr years are described by Gupta and Fernandes (1998). For the sake of brevity and significance the response of the Pyloniid group to natural forcing is presented here.

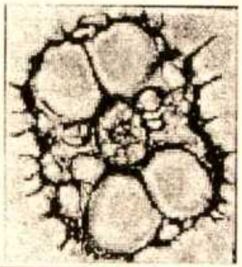
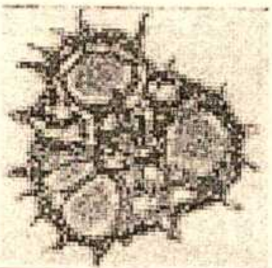
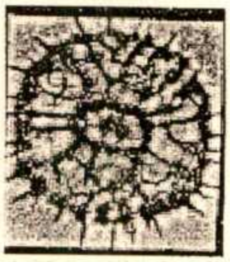
## Results and Discussions

### *Biostratigraphy and Time Control*

As the core-site is below the carbonate compensation depth (< 5000 m) $\delta^{18}O$, radiocarbon and AMS isotopic dating are not possible so that radiolarian biostratigraphy is used to date the core. Two radiolarian datum levels, (i) first appearance datum (FAD) of *Buccinosphaera invaginata* (~180 kyr) at ~185 cm and (ii) last appearance datum (LAD) of *Stylatractus universus* (~425 kyr) at ~435 cm core depths, were identified in core AAS 2/3. These datum levels are based on the palaeomagnetic-biostratigraphic synchronous datum scheme (Johnson *et al.* 1989) for the tropical Indian Ocean. The age versus core depth plot (Fig. 2) suggests a sedimentation rate of ~1 (0.95) cm/1000 years for the core AAS 2/3 and thus base of the core dates to ~500 kyr (± 10 kyr) B.P. Considering that subsampling was a 1cm thick slice at 5 cm intervals, the $\delta t$ (time interval) is ~5000 years and provides a high resolution which qualifies it for the non-aliasic time series for the Milankovitch forcing (23 kyr/4).

### *Response of the Pyloniids Group to Natural Forcing*

The Pyloniid group's percentage constitutes cumulative counts of specimens of *Tetrapyle octacantha* Muller, *Octapyle stenozoa* Haeckel, *Hexapyle dodecantha* Haeckel, and *Phorticium pylonium* Haeckel, belonging to the family Pyloniidae (Gupta 1991: 4, 1996: 1-8) and are reported from the surface waters of all the world oceans (Anderson 1983). Constituent species/genera, references and their percentage distribution in a time-series are presented in Fig. 3. As the timeframe in the core is based only on the radiolarian biostratigraphic datum (accuracy ± 5 kyr), obviously a comparative response to astronomical forcing in climate dynamics is required. The sinusoidal variation of the Pyloniids group in core AAS 2/3 (Fig. 3) apparently has several peaks and troughs composed of multiple minor fluctuations which make the time series difficult to interpret. Therefore, to ascertain the response of the

| **Pyloniids** includes *Tetrapyle octacantha, Octapyle stenozona, & Hexapyle dodecantha* | **Ref**: Mullineaux & Westberg-Smith, 1986, p. 66, pl. 2, fig. 2; Gupta, 1991, pl. 10, figs. 15-21; Gupta & Srinivasan 1992, pl. 2, figs. 15-16.<br>Pyloniids dwell in the surface waters of world oceans. | | |
|---|---|---|---|
| Typical specimens: ***Tetrapyle octacantha*** | ***Octapyle stenozona*** | ***Hexapyle dodecantha*** | ***Pylonimum spp.*** |
| |  |  |  |

**Pyloniids % distribution in time domain**

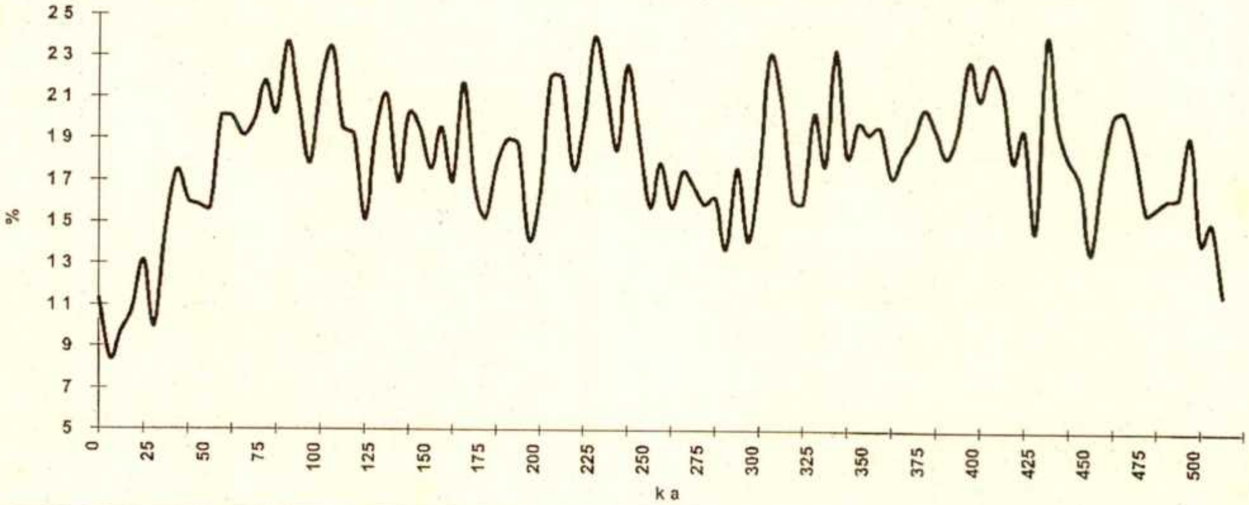


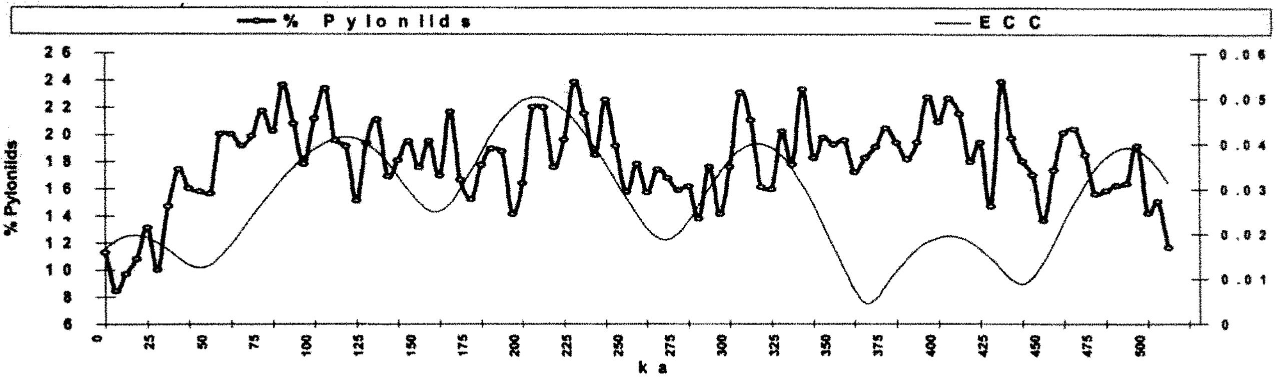
**Fig. 3**: Composition of Pyloniids group, its references, typical specimens and variation in down core for the last 500 kyr years

Pyloniids to natural forcing we calculated the insolation (solar radiation) at 8° S latitude over the core site (AAS 2/3), the eccentricity, obliquity and precession of the earth's orbital forcing at 5-kyr for the last 500 kyr years using the Berger (1977) and Berger and Loutre (1991) formulae by the Analyseries software (Paillard *et al.* 1996), and compared their response (Fig. 4). According to Berger's solutions, the earth's orbital eccentricity has varied between 0.000267 to 0.05733, axial tilt (obliquity) between 22°.08' to 24°.54' and the precession between -0.05625 to 0.05623 during the last 5 million years cyclically at ~405 kyr, 126 kyr and 95 kyr (eccentricity), ~53 kyr, 41 kyr, and 31 kyr (tilt) and ~23 kyr, 19 kyr and 17 kyr (precession) year cycles.

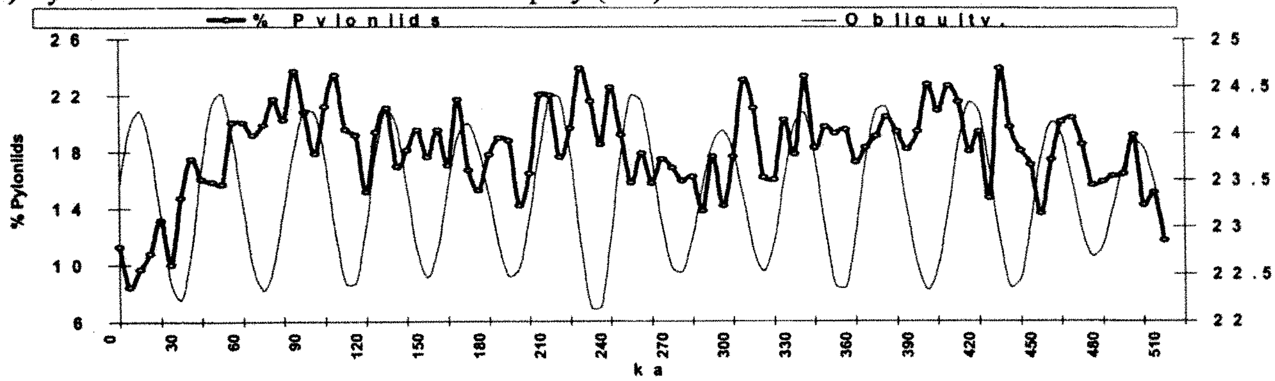
### *Pyloniids versus Earth's Orbital Eccentricity*

The comparison between the Pyloniid variations in percentages and the earth's orbital eccentricity in the last 500 kyr exhibits a convincing peak to peak correspondence between the two time series at almost every 100 kyr (± 5 kyr). This suggests the existence of the 100 kyr eccentricity cycle in the Pyloniids timeseries. Further, the eccentricity minimal peaks at the last 10 kyr and 410 kyr

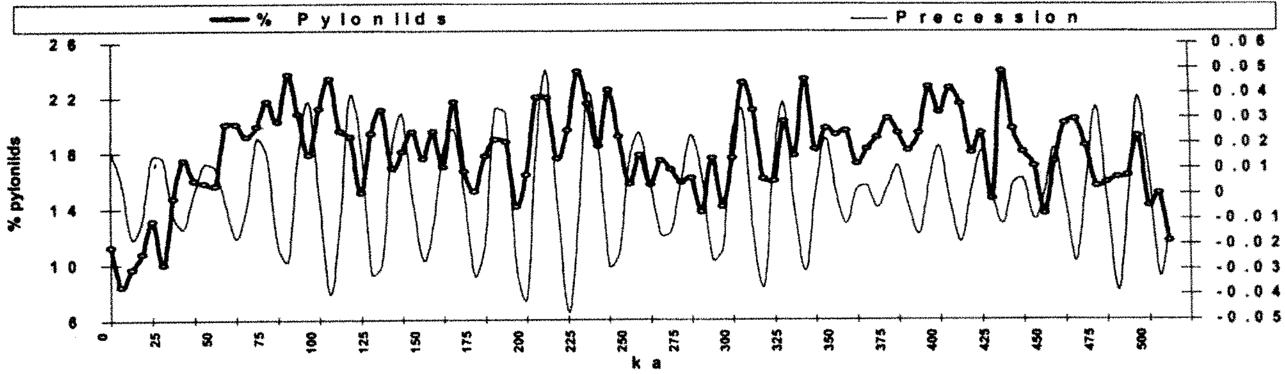
**a)** Pyloniids % versus Earth's orbital eccentricity



**b)** Pyloniids % versus Earth's axial obliquity (Tilt)



**c)** Pyloniids % and Earth's precession



**d)** Pyloniids % versus Solar Insolation at 8° S

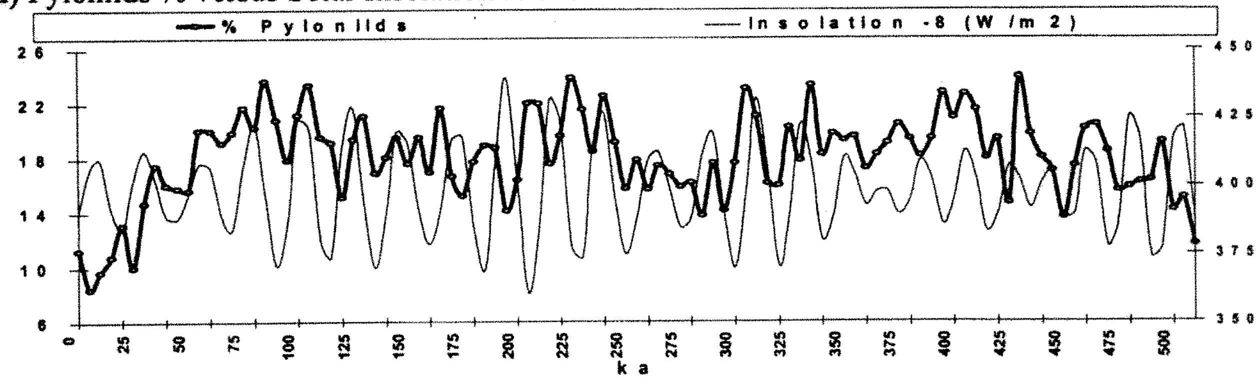
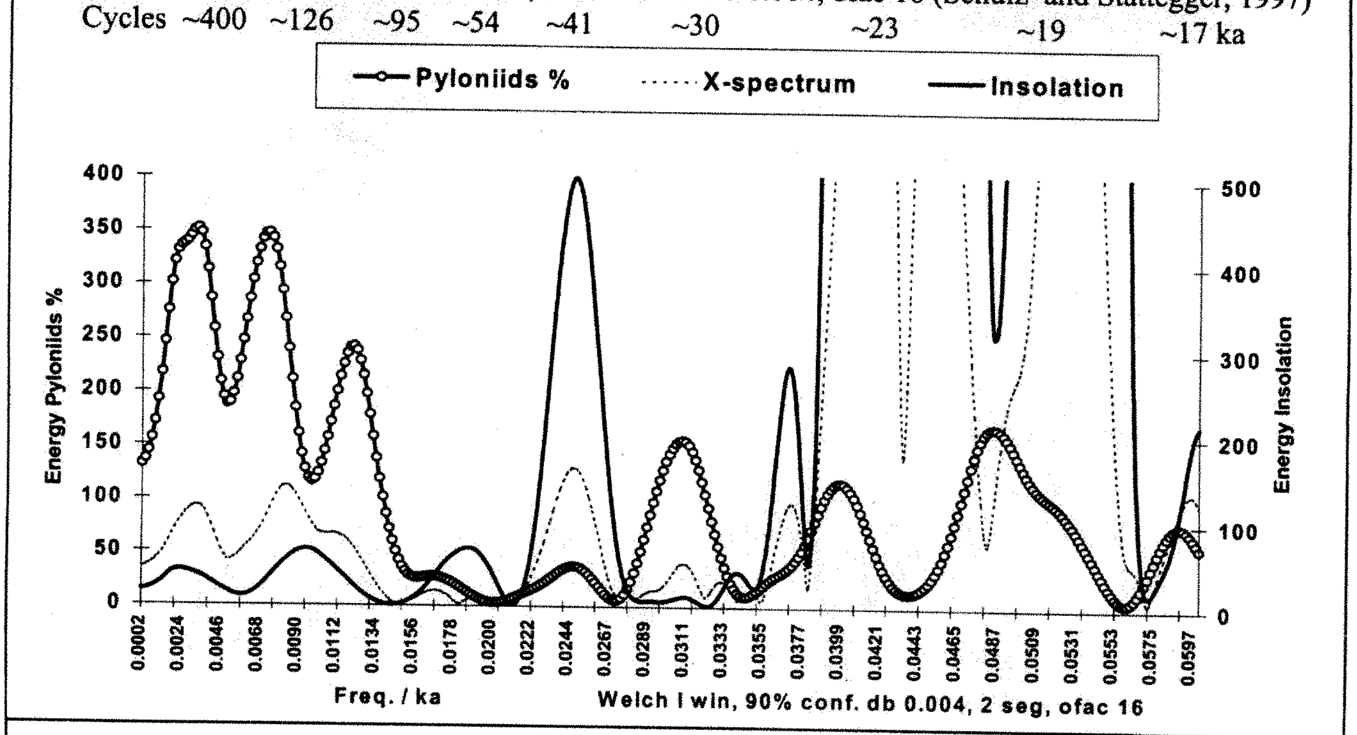


**Fig. 4**: Comparison between the variation in Pyloniids % and the earth's orbital eccentricity, axial obliquity, precession and solar insolation at the core site in the last 500 kyr

**a:** Raw %, welch window, 90% conf., band width d-b 0.004, ofac 16 (Schulz and Stattegger, 1997)



**b:** Gaussian filtered % of Pylonids (Paillard *et al*, 1996) Blackman-Tuckey window, conf. 80%

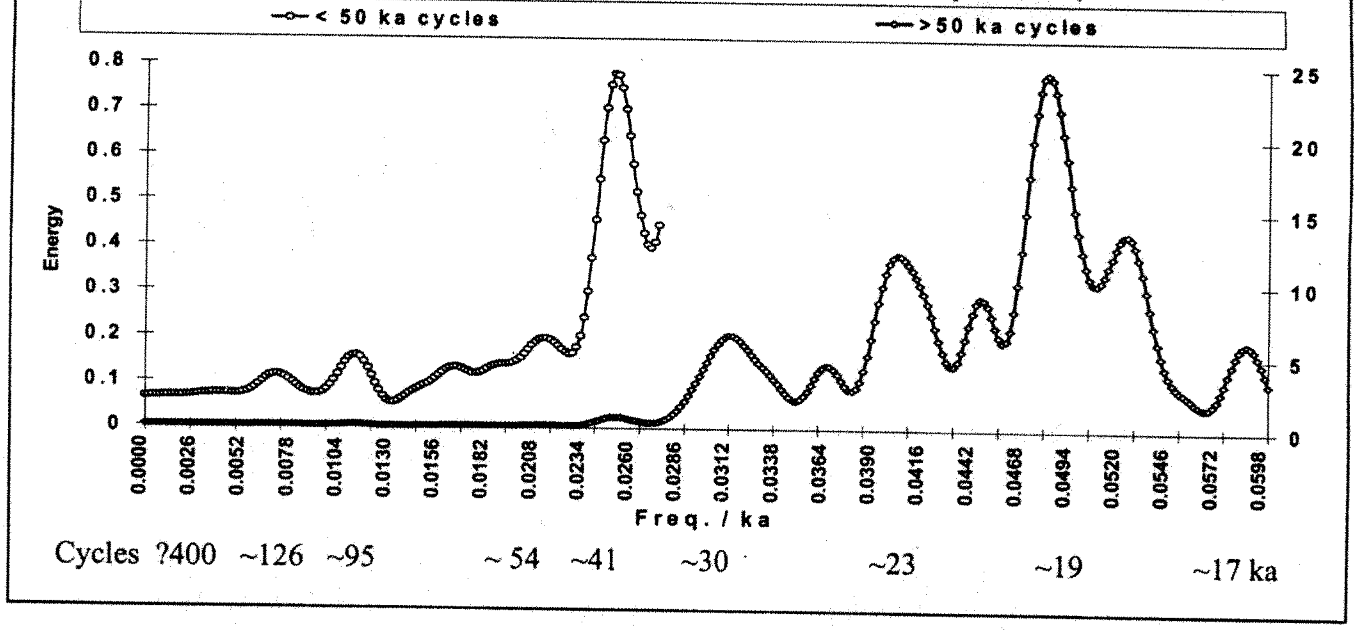


**Fig. 5**: Spectral analyses of the raw percentage of Pyloniids and insolation (a) and Gaussian filtered Blackman Tuckey spectral model (b) showing cyclicities in the time series

represented the 400 kyr cycle, except that its amplitude is higher than the Pyloniid's (Fig. 4a).

### *Pyloniids versus Earth's Axial Obliquity (Tilt)*

A close correspondence between the majority of the peaks and troughs in the Pyloniid percentage variation and the eatrh's axial obliquity in the last 500 kyr is seen. This suggests the existence of the 41,000 year obliquity cycle in the Pyloniid variation (Fig. 4b).

### *Pyloniids versus Earth's Precession*

Pyloniids percentage variation and the earth's precession in the last 500 kyr is shown in Figure 4c. Once more, a striking correspondence between the majority of the peaks and troughs in two time series is seen which suggests the existence of the 23,000 year precession cycle in the Pyloniid variation.

### *Pyloniids versus Solar Insolation at ~8° S Latitude*

Comparison between the Pyloniid percentage variation and solar insolation at ~8° S latitude in the last 500 kyr years exhibits a high correspondence between the majority of the peaks and troughs in the two time series which suggests that solar insolation during the monsoon months may have a strong bearing on the Pyloniids in oceanic climate dynamics (Fig. 4d).

### *Spectral Analyses and Astronomical Cycles*

In order to verify the Pyloniid response to orbital forcing, spectral analyses of Pyloniid's percentage and the incoming solar insolation at 8° S latitude over the core site, was carried out by the Schulz and Stattegger (1997) method (Fig. 5a). The spectral setting used for raw percentages are the Welch I window, 90% confidence, bandwidth 0.004, ofac 16, hifac 1, segment 2 for Figure 5a. Though, the Pyloniids and insolation exhibit cyclic changes at ~400-, 126-, 95-kyr (eccentricity), 54-, 41-, 30-kyr (obliquity) and 24-, 19- and 17-kyr (precession) due to the earth's orbital perturbations (Fig. 5a), the inherent noise may obliterate the signals. Therefore, the 9-point Gaussian filter was used and climate response was re-analysed by Analyseries with the Blackman-Tuckey (BT) window (Paillard *et al.* 1996) which confirmed the presence of 126 kyr, 95 kyr (eccentricity), 41 and 30 kyr (obliquity) and 23, 19 and 17 kyr (precession) year cycles in the Pyloniids (Fig. 5b). The 400 kyr cycle seems to be flattened out by the filter and 1/3 lagging (tappered) BT window, whereas other cycles are prominently present in Figure 5b. Core AAS 2/3 yields one of the best records of climate encountered so far, as it exhibits all the major cycles predicted by Berger (1977: Tables 1-3) due to the earth's orbital dynamics affecting solar insolation. It is noteworthy that core AAS 2/3 contains cycles not reported before from any core with multiple triplet peaks of eccentricity (~400-, 126-, 95-kyr), obliquity (54-, 41-, 30-kyr) and precession (23-, 19-, 17-

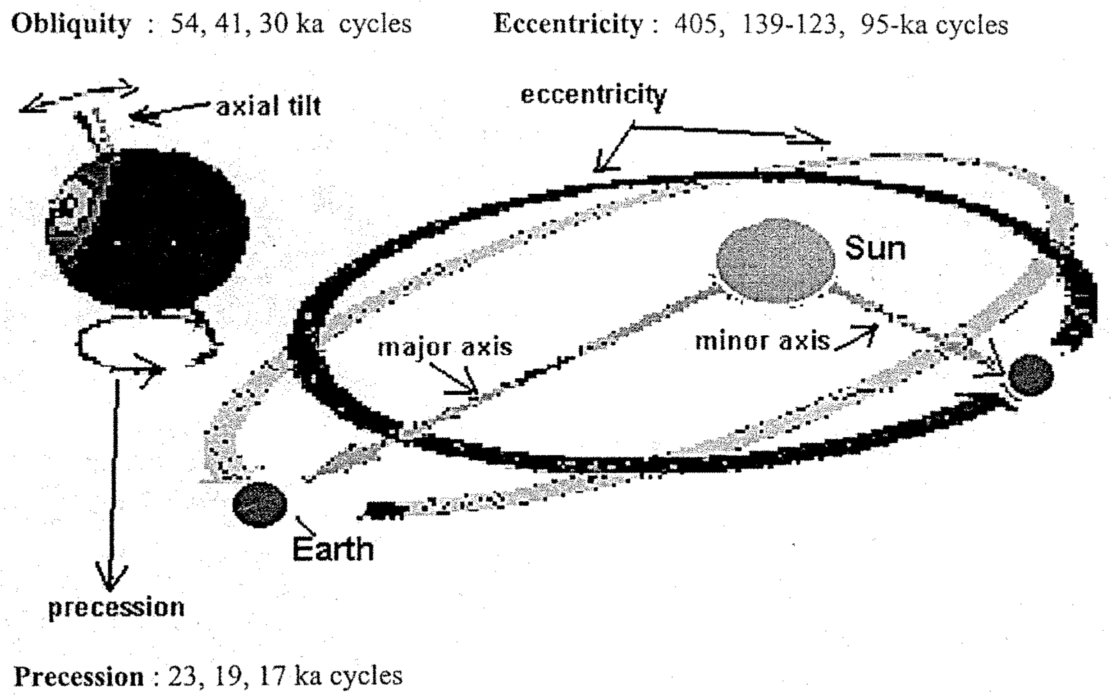

**Obliquity** : 54, 41, 30 ka cycles
**Eccentricity** : 405, 139-123, 95-ka cycles
axial tilt
eccentricity
Sun
major axis
minor axis
Earth
precession
**Precession** : 23, 19, 17 ka cycles

**Fig. 6**: Earth's orbital parameters influencing solar insolation and their astronomical cyclicities in climate dynamics

kyr) conforming to the Milankovitch theory (Fig. 6). These results re-validate our first report of triplet eccentricity peaks (Gupta *et al.* 1996), which were later found by Clemens and Tiedmann (1997) and Muller and MacDonald (1997a, 1997b). Muller and MacDonald (1997a, 1997b) have discussed the 100 kyr cycles due to the eccentricity ($e$) at length and argued for assigning it to the inclination ($i$) of the Earth's orbital plane as the eccentricity should have triplet peaks of 400 kyr, 126 kyr and 95 kyr cycles. An excellent review of the problem of eccentricity versus inclination causing the 100 kyr cycle may be found in Kerr (1997) as it is out of the scope of the present paper. Once the SSTs and salinity estimates are generated, they will provide a better insight into the terms of thermal amplitude changes in the tropical ocean which in turn would have a bearing on regional, tropical climate dynamics.

## Conclusion

This study suggests that like terrestrial life, oceanic biota called "Pyloniids" also are affected by climatic changes and respond to natural climate forcing such as solar insolation, the earth's orbital eccentricity (~400-, 126-, 95-ka), axial obliquity (41-, 30-ka) and precessional (23-, 19-, 17 ka) cycles. It is noteworthy that Pyloniids have striking triplet peaks in the eccentricity band as postulated by Berger (1997), and found by Gupta *et al.* (1996), Clemens and Tiedmann (1997) and Muller and MacDonald (1997a, 1997b). This study also strengthens the data base that enhances the role of orbital eccentricity in climate dynamics, earlier thought to be minimal in previous studies. The Pyloniid group exhibits responses to astronomical forcing such as solar radiation (insolation), earth's orbital eccentricity, axial obliquity and precessional perturbations. The study suggests that the Pyloniid radiolarian group may serve as a proxy for the changes in the monsoon in the tropical Indian Ocean and can be used in the reconstruction of the palaeomonsoon in the geological past.

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# Late Holocene Temporal Patterns of Palaeofloods in Central and Western India

Vishwas S. Kale

Department of Geography,
University of Pune,
Pune 411 007

## Abstracts

This paper briefly summarizes the evidence of palaeofloods on five large rivers in central and western India. The preliminary synthesis of the palaeoflood data indicates century-scale variations in the flood frequency and a noteworthy clustering of large floods during the late Holocene period. On the basis of modern analogues it appears that the century-scale variations in flood frequency and magnitude are linked to long-term fluctuations in the monsoon precipitation.

## Introduction

In recent years, proxy data such as sedimentologic deposits, fluvial features, tree-ring records, etc. have become an important source of palaeohydrologic and palaeoclimatic information in many arid and semi-arid regions of the world. Evidence of long-term hydrologic variability is preserved in fluvial sediments (Jarrett 1991). The analysis of these sediments, therefore, not only provides information about long-term streamflow variability (i.e. mean discharges), but also the magnitude and frequency of individual large floods. Palaeoflood hydrology is concerned with the later, and is primarily based on the analysis of flood sediments termed as slackwater deposits (Baker 1987).

Slackwater deposits (SWD) are typically fine-grained sand and silt that accumulate in areas of reduced flow velocity (Baker 1987; Kochel and Baker 1988). Such areas include backflooded tributaries, meander bends, caves, and abrupt channel expansions and contractions (Baker and Kochel 1988; Kochel and Baker 1988). Repeated occurrence of large floods leaves a continuous stratigraphical record of floods in protected niches. This type of palaeohydrological evidence together with accurate radiocarbon and/or luminescence dating provides a long ($10^2$ to $10^3$ years) record of ancient or palaeofloods (Baker 1987; Ely 1997). The length of the palaeoflood record on a single river depends upon the extent of preservation of SWD from subsequent erosion by the river.

Tropical rivers in general, and monsoon-dominated rivers in particular, have proved to be good recorders of palaeofloods (Baker 1995). Many rivers of central and western India are well suited for the accumulation and preservation of thick sequences of palaeoflood slackwater sediments in backflooded tributaries (Fig. 1) because of
(1) conducive geomorphic situations, in terms of an abundance of stable bedrock channels/gorges,
(2) favourable lithologic conditions, in terms of abundant production of silt and sand sized sediments, and (3) their location in the track of flood-generating monsoon depressions and storms. Consequently, during the last one decade many studies have focused on the use of slackwater deposits to reconstruct the flood chronology of these monsoonal rivers (Baker 1988; Kale *et al.* 1994; Ely *et al.* 1996; Kale *et al.* 1997).

This article briefly summarizes the evidence of palaeofloods on five large rivers in central and western India. The main objectives of this paper are: 1) to identify the temporal patterns in large floods during the late Holocene, 2) to identify great periods of high and low floods, and 3) to examine the relationship between flood regime conditions and the palaeoclimate.

## Palaeoflood Records in Central and Western India

Many rivers in central and western India contain slackwater deposits, and more than ten SWD sites have now been located and well documented (Fig. 2). The important characteristics of eight major palaeoflood sites are summarized in Table 1.

In terms of thickness, number of flood units, state of preservation, and availability of datable material, the characteristics of palaeoflood records vary significantly (Table 1). The maximum thickness of the slackwater deposits varies from 3 to 10 m, and between 11 and 37 floods are documented in these deposits (Table 1). Tributary mouths are the most common geomorphic sites for the accumulation of slackwater sediments. A large number of

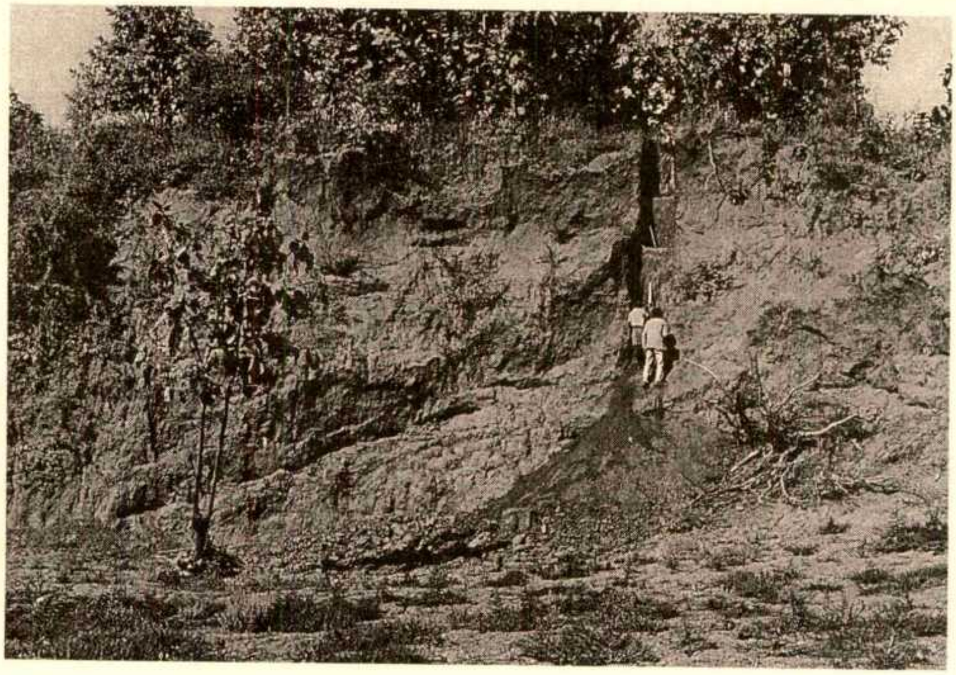

**Fig. 1**: Thick sequence of palaeoflood slackwater sediments in an unnamed backflooded tributary of the Narmada River at Sakarghat near Punasa, Madhya Pradesh. The deposits are more than 6.5 m thick and contain evidence of at least 26 palaeofloods that have occurred during the last 2 ka

**Table 1**: Palaeoflood records in central and western India

| River | Gorge | Site | Geomorphic situation | Max. thickness of SWD m | Number of floods | Length of the record in c. ka | Number of large post-1950 floods |
|---|---|---|---|---|---|---|---|
| Narmada | Punasa | Sakarghat | at the confluence with a small ephemeral, backflooded tributary | 6.5 | 26 | 2.0 | 3 |
| Narmada | Punasa | Chahin Nala | upstream of a small backflooded tributary | 5.0 | 11-15 | 1.7 | 4-5 |
| Narmada | Punasa | Chota Tawa | at the confluence of a large backflooded tributary | 4.0 | 14-15 | 1.4 | 4 |
| Narmada | Punasa | Ramghat | at the confluence of a small backflooded tributary | 2.5 | 18-19 | 0.6 | 4 |
| Godavari | Papikonda | Pochavaram | near the confluence of a small backflooded tributary | 4.5 | 32 | 2.1 | 1 |
| Krishna | Srisailum | Srisailum | at the confluence of a large backflooded tributary | 10.5 | >37 | 1.0 | 1 |
| Tapi | Bhainsadehi | Ghuttigarh-Khapa | at the confluence of a small backflooded tributary and meander bend | 3.0 | 13-16 | 0.4 | 1-5 |
| Luni | Sindari | Bhuka | upstream of a small ephemeral backflooded tributary | 3.0 | 17-22 | 1.0* | 1 |

(Source: Ely *et al.* 1996; Kale *et al.* 1997; Kale *et al.* in preparation); * based on OSL dates

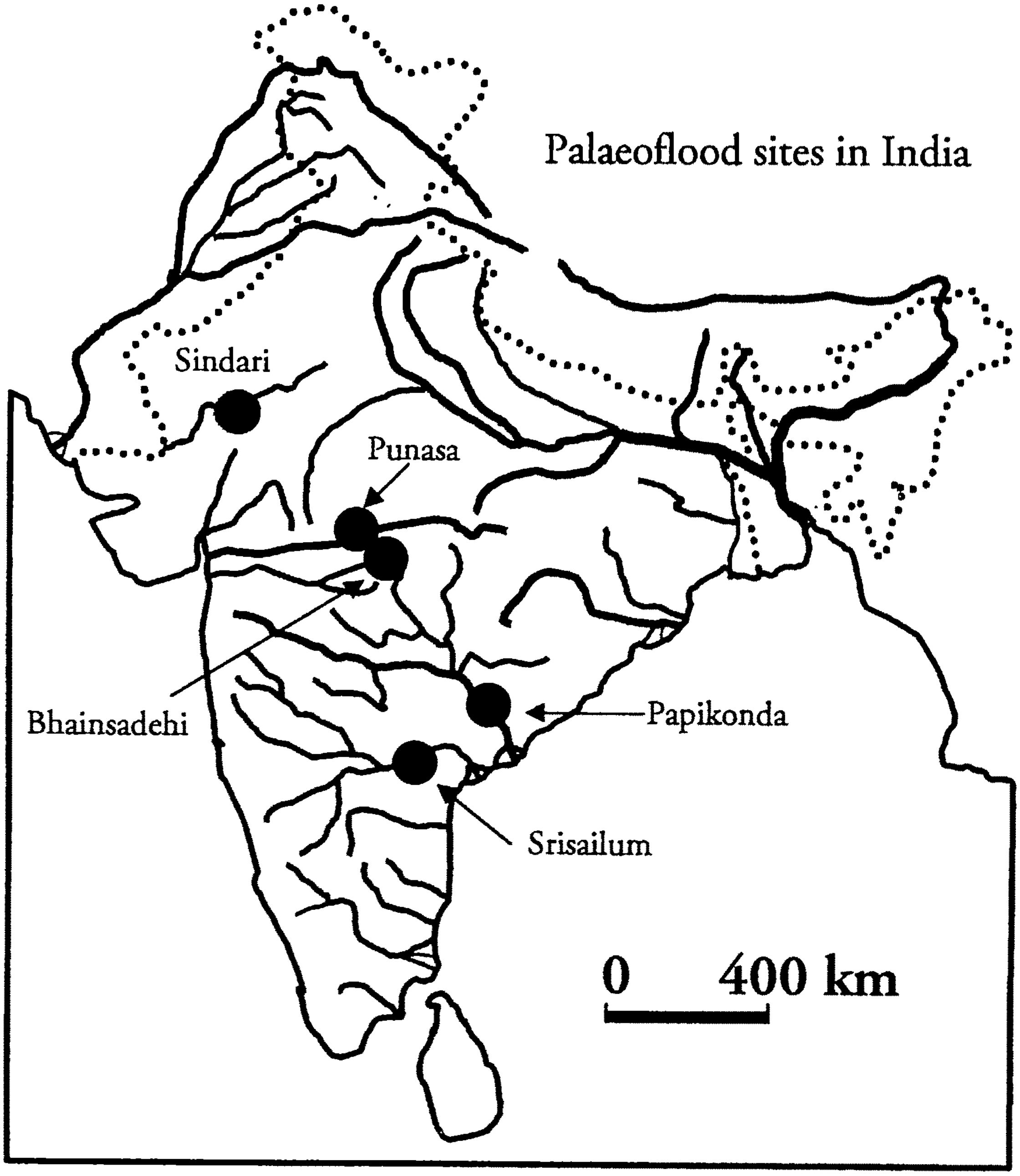

**Fig. 2**: Location of slackwater flood deposit sites in India

conventional $^{14}$C, AMS and OSL dates, and archaeological material suggest that most sites have preserved sedimentary records of multiple floods that have occurred between the last few centuries and about two millennia.

Even though the variable length of the palaeoflood records and the variable age resolution precludes the identification of great periods of high and low floods on the regional scale, a preliminary synthesis of the palaeoflood records yields some interesting patterns (Fig. 3). The synthesis indicates distinct century-scale variations in the flood frequency, and temporal clustering of large floods during the late Holocene period. One of the most notable characteristics that emerges is the marked absence of large-magnitude floods on most rivers generally during last 700 years, and particularly between 700 and 400 yrs B.P. This period coincides with the late Middle ages (around 1300 to 1600 A.D.) (Ely 1997) and the Little Ice Age (c. 1500 A.D. to the late 1800s) (Ely 1997). Evidence of clustering of low-frequency, extreme floods between 1000 and 1600 yrs B.P. (400 and 1000 AD) is provided by

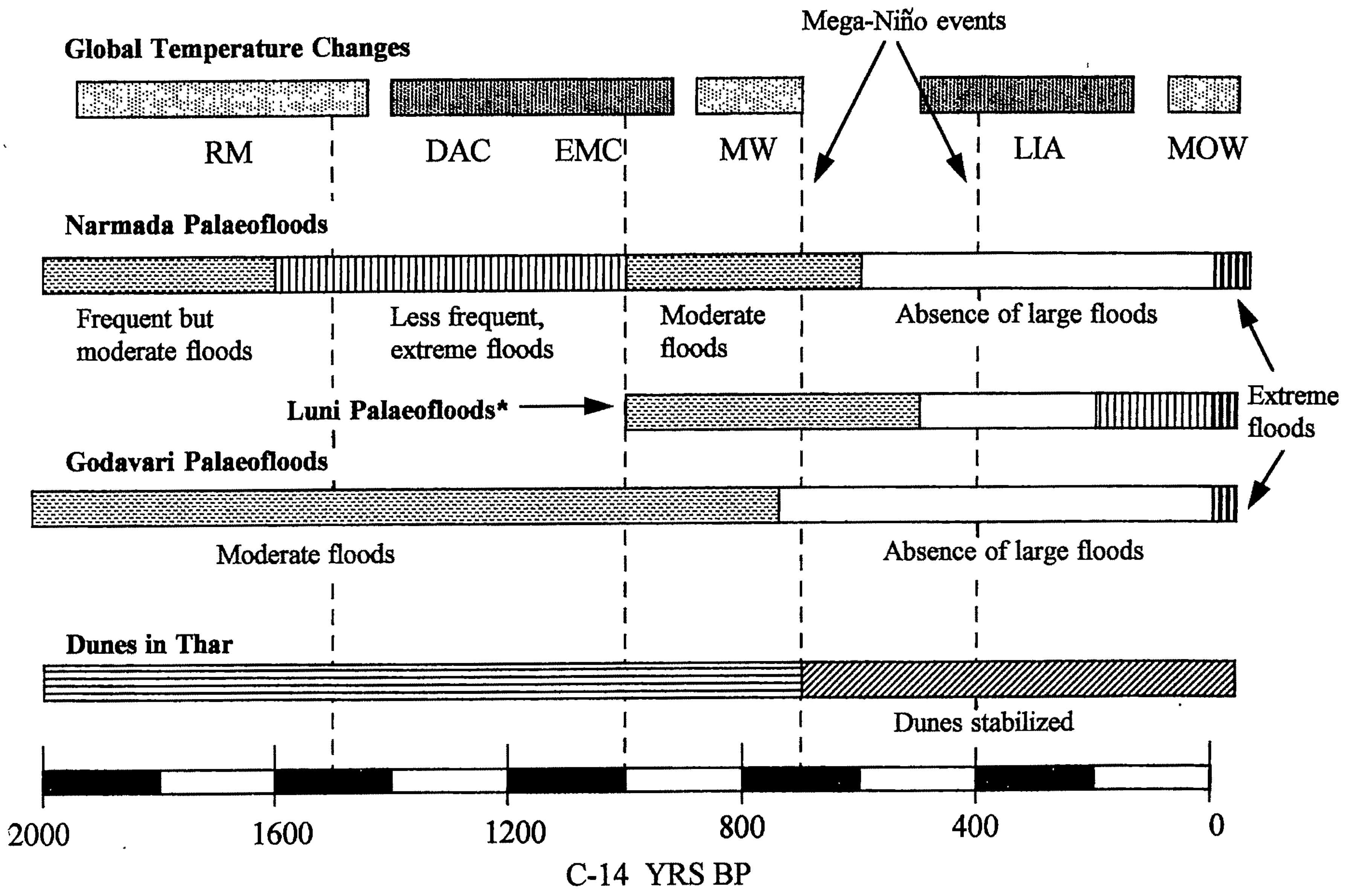

**Fig. 3**: A 2000-year palaeoflood chronology for central and western India, based on several references given in the text. The Late Holocene climatic changes recognized over widespread areas of the globe are given for orientation. RM = Roman Warm; DAC = Dark Ages Cold; EMC = Early Medieval Cool; MW = Medieval Warm; LIA = Little Ice Age; MOW = Modern Warm. * = OSL dates. Note: Onset and termination of all periods approximate

the slackwater deposits preserved at Sakarghat along the Narmada River (Kale *et al.* 1997) (Fig. 1). Another very interesting feature in the palaeoflood records is the remarkable concentration of the largest monsoon floods into the most recent time period (post-1950).

## Palaeofloods and the Monsoon

The distinct variations in the frequency of large floods during the Late Holocene period suggest a regionally widespread causative phenomenon (Ely *et al.* 1993; Baker 1995; Ely 1997). The most likely one being the fluctuations in monsoon precipitation in response to large-scale changes in atmospheric conditions. To establish these kinds of links on a long timescale it is necessary to find modern analogues that can relate episodes of high floods with periods of above-average monsoon precipitation.

Several recent studies have examined the meteorological processes associated with modern floods in India. These studies indicate that large floods are not randomly spaced, but cluster into discrete time intervals, and correspond with periods of above-average monsoon rainfall (Kale 1999; Kale *et al.* in preparation). The analyses further indicate that the flood frequency has varied with the decadal-scale shifts in the all-India monsoon rainfall conditions (Kale 1999).

The decadal-scale fluctuations in monsoon precipitation have been attributed to large climatic variations in the Asian monsoon region, and the El Niño/Southern Oscillations (ENSO) activity. Studies by Fu and Fletcher (1988), Parthasarathy *et al.* (1991) and others indicate that the period 1901-1940 was characterized by a stable zonal pattern in upper atmospheric circulation, and less stable

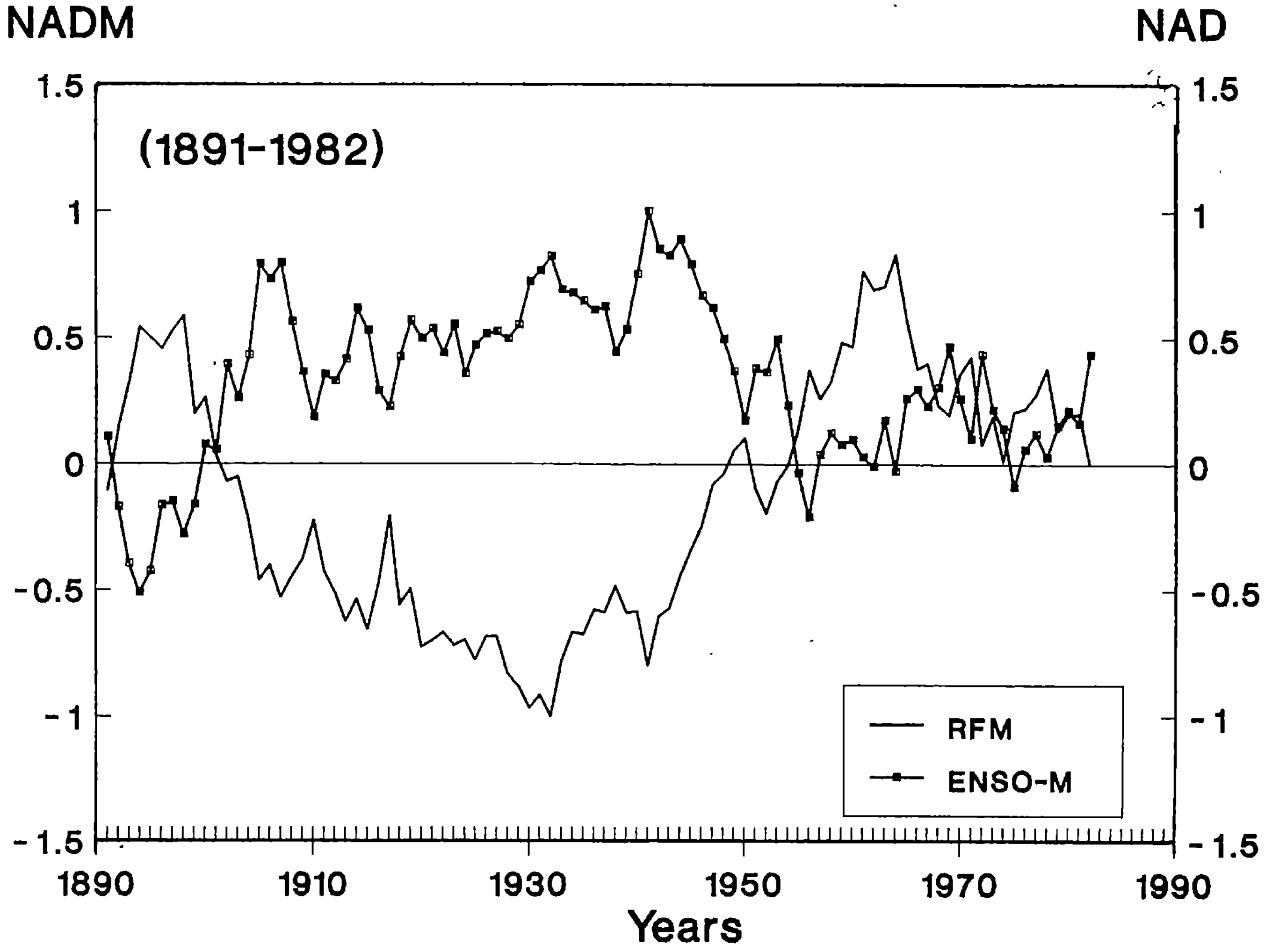

Fig. 4: Graph showing the association between all-India monsoon rainfall (RFM) and SST index of ENSO for the monsoon period (ENSO-M). The normalized accumulated departure from mean (NADM) is the accumulated departure from mean divided by the largest number in order to plot between 1 and +1 (Thomas 1993). NAD is the normalized accumulated mean sea surface temperature (SST) anomaly or departure. The mean SST anomaly is the SST index of ENSO. The ENSO-M is the average index for the monsoon period. SST anomalies data published by Wright (1989)

meridional monsoonal conditions have prevailed after 1940. Through teleconnections with large-scale phenomena such as ENSO, variations in the monsoon rainfall have been linked to circulation patterns across the globe (Rasmusson and Carpenter 1983; Bhalme and Jadhav 1984; Parthasarathy *et al.* 1991; Whetton and Rutherfurd 1994). The strong teleconnection between the sea surface temperature (SST) anomalies over the Pacific Ocean for the monsoon season (ENSO-M) and the all-India monsoon rainfall (RFM) is illustrated in Figure 4. The graphs reveal that the ENSO-M curve rises rapidly (period of positive anomalies) around 1900 A.D. and descends rapidly (period of negative anomalies) in the 1940s. This period, 1900-1940, of relatively low rainfall over India (Parthasarathy *et al.* 1991) and below average floods in the Deccan Peninsula (Kale 1999) coincides with the zonal monsoonal period over the India Ocean (Fu and Fletcher 1988).

The link between monsoon rainfall and large-scale phenomena such as ENSO is further indicated by the coincidence between the decadal-scale shift in the monsoon regime conditions and certain El Niño events over this century. Analysis of the all-India monsoon rainfall data shows a major shift in the precipitation regime conditions around 1877, 1898, 1932, 1964 and 1987 (Kale 1999). The correspondence of these years with some strong or moderate El Niños (Kale 1999) suggests that the activity of the Indian monsoon is strongly teleconnected to SST anomalies over the Pacific Ocean and associated ENSO parameters (Parthasarathy *et al.* 1991).

This modern analogue implies that the same type of fluctuations in the monsoon precipitation are the most likely cause of long-term variations in palaeofloods over the last 2 ka, because the main features (location, mean intensities and variance) of the atmospheric circulation have remained constant throughout the Holocene (Wendland 1989). The link between palaeofloods and late Holocene temperature changes recognized in widespread areas of the globe also lends support to this inference (Fig. 3). Further, in this connection it is important to note that, similar to the decadal-scale shifts in precipitation conditions in the modern records (around 1877, 1898, 1932, 1964 and 1987), the distinct changes in the palaeoflood conditions also correspond with mega-Niño events that occurred around 1500, 1000, 700 and 400 yrs B.P. (Meggers 1994) (Fig. 3).

The distinct period of decline in the frequency of the large-floods during the last 700 years broadly corresponds with the widespread Little Ice Age (c. 1500 A.D. to the late 1800s) (Ely 1997) In northwestern India, this phase is characterized by a period of low rainfall (c. 1600-1900 AD) (Bryson and Swain 1981), and in the Thar desert, this period is represented by a phase of regionally extended landscape stability (Singhvi *et al.* 1994; Kar *et al.* in press). The period of low frequency, but extreme floods between 1 and 1.6 ka coincides with the Dark Ages Cold/early Medieval Cool period (Fig. 3), which has been one of a noteworthy decline in human settlements in northern India (Sharma 1987).

Further, the available gauge and historical records also suggest that no floods comparable in magnitude to the post-1950 floods have occurred, at least, in the last 100-150 years, and thus support the inferences drawn on the basis of palaeoflood records. Interestingly, the clustering of the largest flood events during the post-1950 period is not just confined to the Indian region, but has also been detected in other tropical regions such as southwest USA (Ely *et al.* 1993; Ely 1997) and western Australia (Wohl *et al.* 1994).

A large body of evidence, therefore, suggests that the long-term fluctuations in the frequency of floods is not independent of long-term variations in monsoon precipitation, and are linked to large-scale shifts in global circulation patterns and ENSO activity on the centennial-scale.

## Conclusion

This preliminary synthesis of palaeoflood data from five large rivers in central and western India shows distinct century-scale variations in flood frequency and a noteworthy clustering of large floods during the late Holocene period. The preliminary results further indicate a period of significantly reduced frequency of large floods during the late Medieval and the Little Ice Age (c. 1500 A.D. to the late 1800s) and an enhancement in the magnitude and frequency of large floods in the post-1950 period. The last 1000 years of relatively better resolution palaeoflood records demonstrate a good association between palaeofloods and the late Holocene climatic changes recognized in widespread areas of the globe (Fig. 3). On the basis of modern analogues it appears that the century-scale variations in flood frequency and magnitude are linked to long-term variations in the monsoon precipitation, which, in turn, are teleconnected to the large-scale shift in global circulation patterns and the ENSO activity.

Needless to say more studies and more proxy data are needed to confirm this patten. There are, therefore, abundant directions for future research in this area of palaeohydrology and palaeoclimatology.

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# Decadal Rainfall Prediction Across India Using Longest Instrumental Records

N.A. Sontakke and Nityanand Singh

Indian Institute of Tropical Meteorology
Dr. Homi Bhabha Road, Pashan
Pune 411 008

## Abstract

Long period rainfall series are vital in studies of climate variability as well as being useful in cross comparisons with climatological proxies such as tree-rings, microorganisms in marine cores, lake sediments, preserved pollens, ice cores, etc. In this paper reconstructed longest instrumental rainfall series are modelled and extrapolated to predict rainfall fluctuations over a 10-yr period (1998-2007) across the country. This study uses summer monsoon rainfall (SMR), post-monsoon rainfall (PMR) and annual rainfall series of northwest India (NWI), north central India (NCI), northeast India (NEI), west peninsular India (WPI), east peninsular India (EPI), south peninsular India (SPI) and relatively-plain-and-contiguous (REPAC) India (combined area of the stated six zones), and also the rainfall series of each of the four seasons and annual total of north mountainous India (NMI) (combined area of hills of Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir). A brief description of the reconstruction of the different series using optimum observations is provided. Some series have been extended back to 1813, and all are updated up to 1997.

The low frequency smoothed series up to 1997 plus the series 1998-2007, filled with the long term mean is subjected to Variable Harmonic Analysis (VHA). VHA is a modification of classical harmonic analysis. An objective technique is applied to select a few harmonics whose linear combination showed a correlation coefficient of ~ 0.85 with the smooth series. The rainfall amount generated from the selected harmonics would be the prediction for the period 1998-2007. The study provides a tentative inference that rainfall fluctuations across the country are likely to be around the long term mean over the next 10-yr period.

## Introduction

Long period instrumental series are vital in studies on historical climatic variability, including understanding, modelling, monitoring and prediction. They are also useful in cross-comparisons with climatological proxies such as tree-rings, microorganisms in marine cores, lake sediments, preserved pollens, ice cores, etc. Representative climatic time series prepared using adequate instrumental observations are available only for short periods. In the past few decades, attempts have been made to reconstruct climatic time series of the longest possible period using the limited isolated instrumental observations available in government or private archives. The instrumental data provides a numerical and quantitative basis to study climate and its variability. A review of numerous studies which attempt to reconstruct temperature variations from the instrumental data in order to verify the cooling during the Little Ice Age (A.D. 1450-1890) is given by Crowley and North (1991). Some important small scale reconstructions are: monthly mean air temperature in England during A.D. 1680-1706 and 1698-1957 (Manley 1958,1961), temperature and precipitation in the Netherlands A.D. 1715 and 1706 (Labrign 1945), central England temperature monthly means between A.D. 1659-1973 (Manley 1947a), monthly precipitation over England and Wales during A.D. 1727-1931 (Nicholas and Glasspoole 1931), monthly and annual precipitation for Kew Observatory, U.K. during A.D. 1697-1970 (Wales-Smith 1971), monthly and annual precipitation series of England and Wales of A.D. 1766 (Wigley *et al.* 1984b), monsoon precipitation series for Western Sahel between A.D. 1899-1990 (Christopher *et al.* 1992), Manchester precipitation of A.D. 1765 (Manley 1974b), Beijing precipitation between A.D. 1470-1974 (Hameed *et al.* 1983), precipitation at Padova, Italy from A.D. 1725 to 1981 (Camuffo 1984), precipitation at Rome between A.D. 1782 and 1978 (Colacino and Purini 1986), precipitation at Athens, Greece: A.D. 1858-1985 (Katsoulis, 1989), precipitation at Cirencester during A.D. 1844-1977 (Jones 1980) and summer monsoon rainfall of India during A.D. 1871-1978 (Mooley and Parthasarathy 1984).

Some of the hemisphere scale reconstructions are, annual temperature series of the northern hemisphere during A.D. 1899-1975 (Landsberg *et al.* 1978), northern hemispheric temperature departures between A.D. 1579 and 1880 (Groveman and Landsberg 1979), northern hemispheric land area precipitation from A.D. 1850 to 1983 (Bradley *et al.* 1987), northern hemispheric surface air temperature between A.D. 1851-1984 (Jones *et al.* 1986a), southern hemispheric surface air temperature from A.D. 1851 to 1984 (Jones *et al.* 1986b), El-Niño occurrences between A.D. 1525-1983 (Quinn and Neal 1987), northern and southern hemispheric temperature series (A.D. 1891-1988), and precipitation series for the years between A.D. 1891 and 1987 (Vinnikov *et al.* 1990).

Sontakke and Singh (1996) have reconstructed the longest instrumental records of summer monsoon (June to September total) rainfall. The series for which this has been done are: -relatively-plain-and contiguous (RPC) India and its six homogeneous zones — northwest India (NWI), north central India (NCI), northeast India (NEI), west peninsular India (WPI), east peninsular India (EPI) and south peninsular India (SPI). Later, annual rainfall and post-monsoon (October to December total) rainfall series for these regions were reconstructed by Singh and Sontakke (1996, 1999). For north mountainous India (NMI) (the combined area of the hills of Uttar Pradesh, Himachal Pradesh and Jammu and Kashmir), the instrumental rainfall series for each of the four seasons (winter, summer, summer monsoon and post-monsoon) and the annual total are reconstructed and reported in this paper. The present study was motivated by the need to explore the scope for the prediction of rainfall fluctuations over a 10-yr period across the country by the extrapolation from these long period series. Similar attempts were made by Scheckedanz and Bowen (1977) and Kane and Teixeiro (1990) and others earlier.

## The Seven Rainfall Zones of the Country

Over the vast geographical area of the country (32,80,483 km$^2$) the spatial variability in rainfall occurrences is quite large. Sontakke and Singh (1996) have divided the relatively-plain- and-contiguous (RPC) portion of the country (excluding mountainous areas of Uttar Pradesh and states of Jammu and Kashmir, Himachal Pradesh, Arunachal Pradesh and islands in the Bay of Bengal and Arabian Sea, total area 28,80,049 km$^2$) into six zones for the effective studies of summer monsoon rainfall (SMR), particularly its long range forecast. This portion will be referred to here as the REPAC India. SMR data of well spread 306 raingauge stations for the period A.D. 1871-1984 was analyzed by four methods to define the spatially coherent stations in respect of SMR fluctuations. The methods are: (i) obtaining a correlation coefficient between REPAC India SMR and the individual gauges for the period 1871 to 1980 A.D.; (ii) determining the change in mean SMR for the periods 1901-1940 A.D. and 1941-1980 A.D. at the individual sites; (iii) the S-mode empirical orthogonal function analysis of the SMR series; and (iv) a cluster analysis based on the correlation coefficient, and the distance coefficient between the gauges. Subjective judgmental approaches were used on the results of the analyses to carefully choose the geographic meridians and parallels to divide the country into the following zones (Singh and Sontakke 1996; Sontakke and Singh 1996; Fig. 1):

| | |
|---|---|
| Northwest India (NWI): | north of 21°N latitude and west of 80°E longitude. |
| North central India (NCI): | north of 21°N latitude and between the longitudes of 80° and 88°E. |
| Northeast India (NEI): | north of 21°N latitude and east of 88°E longitude. |
| West peninsular India (WPI): | between the latitudes of 15° and 21°N and west of 79°E longitude. |
| East peninsular India (EPI): | between the latitudes of 15° and 21°N and east of 79°E longitude. |
| South peninsular India (SPI): | south of 15°N latitude. |

The combined area of the hills of Uttar Pradesh, Jammu and Kashmir and Himachal Pradesh constitutes an additional rainfall zone for the present study. This geographical zone covering an area of 3,16,691 km$^2$ will be referred to as the north and mountainous India (NMI). There are 11 raingauge stations in this zone for which long period records are available.

## Longest Instrumental SMR Series for the REPAC India and its Six Zones

For the period A.D. 1871-1984, the representative area-averaged SMR series for REPAC India and its six zones were prepared using data from the 306 raingauge sites. The arithmetic mean of all the 306 gauges was calculated for the REPAC India series and the gauges in the respective zone for the zonal series. In this network of 306 raingauge stations, 116 gauges are in NWI, 65 in NCI, 25 in NEI, 37 in WPI, 22 in EPI and 41 in SPI. Details of this data set are given in Mooley and Parthasarathy (1984). However, due to the difficulties and time-consuming and cumbersome processes involved in getting the data from all the 306 stations, the number of observations for the different zonal SMR series (as well as REPAC India) were optimized using established objective techniques (Singh 1994; Sontakke *et al.* 1993; Wigley *et al.* 1984b) for updating them on a near-real time basis. From the network of 306

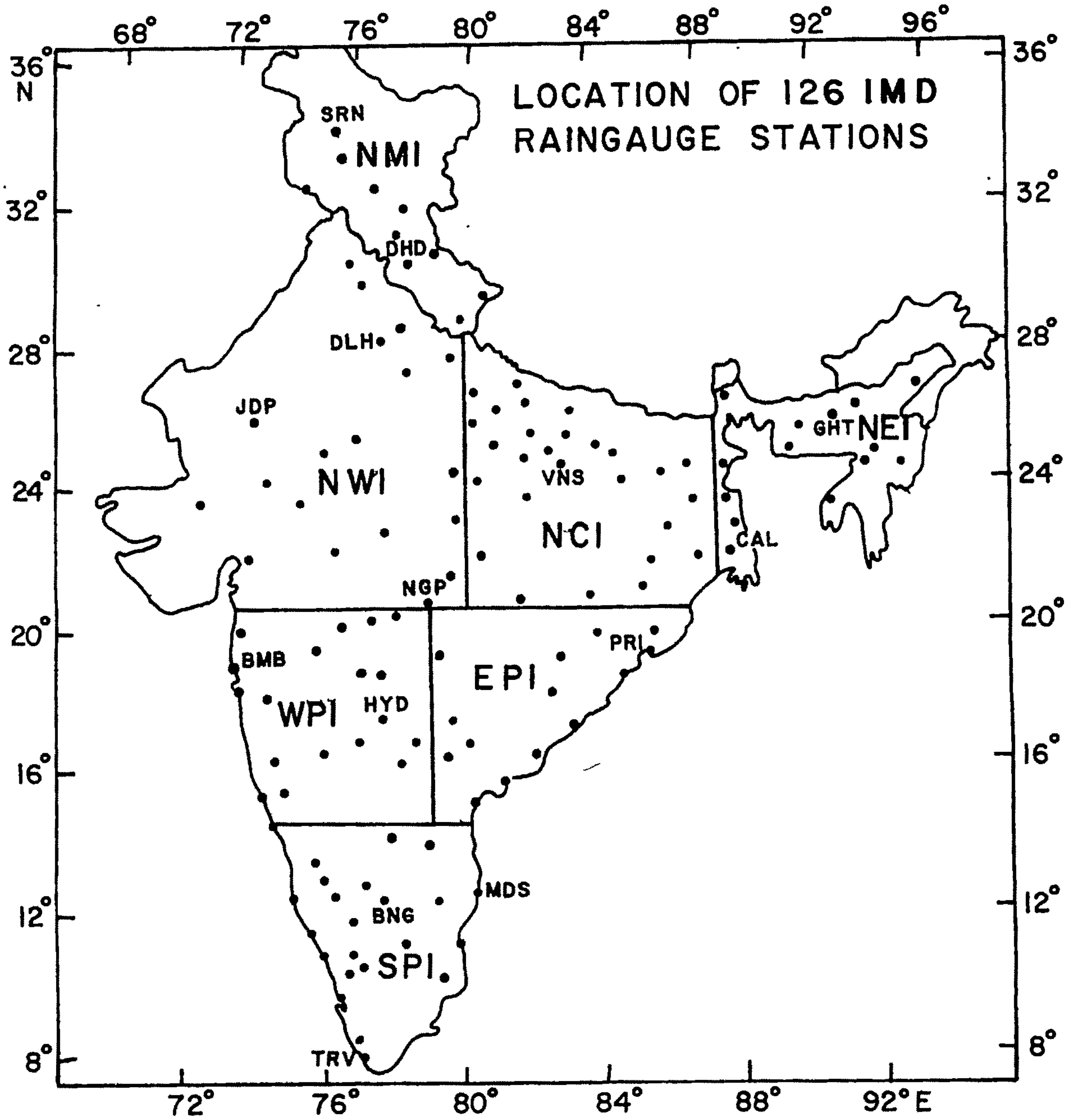

**Fig. 1:** The seven rainfall zones of the country. Dot gives location of 127 IMD raingauge stations for updating the seasonal and annual rainfall series of the different zones and the country

stations, 116 raingauges maintained by the India Meteorological Department (IMD) were identified. The IMD gauges are known for the timely availability of quality controlled data. Of these 116 IMD stations 19 are in NWI, 27 in NCI, 15 in NEI, 18 in WPI, 14 in EPI and 23 in SPI. The REPAC India series was updated from the area-weighted mean of the zonal estimates.

The individual series were also extended backward prior to A.D. 1871 to the maximum possible extent. Year by year, the reconstruction was carried out using an objectively selected subset for that year, whose linear combination showed the highest (and significant at least at 5% level) correlation with the representative series (A.D. 1871-1980). The NWI series was extended back to A.D. 1844, NCI to A.D. 1842, NEI and EPI to A.D. 1848, WPI to A.D. 1817 and SPI and REPAC India to A.D. 1813 (Sontakke and Singh 1996). The different series are displayed in Figure 2.

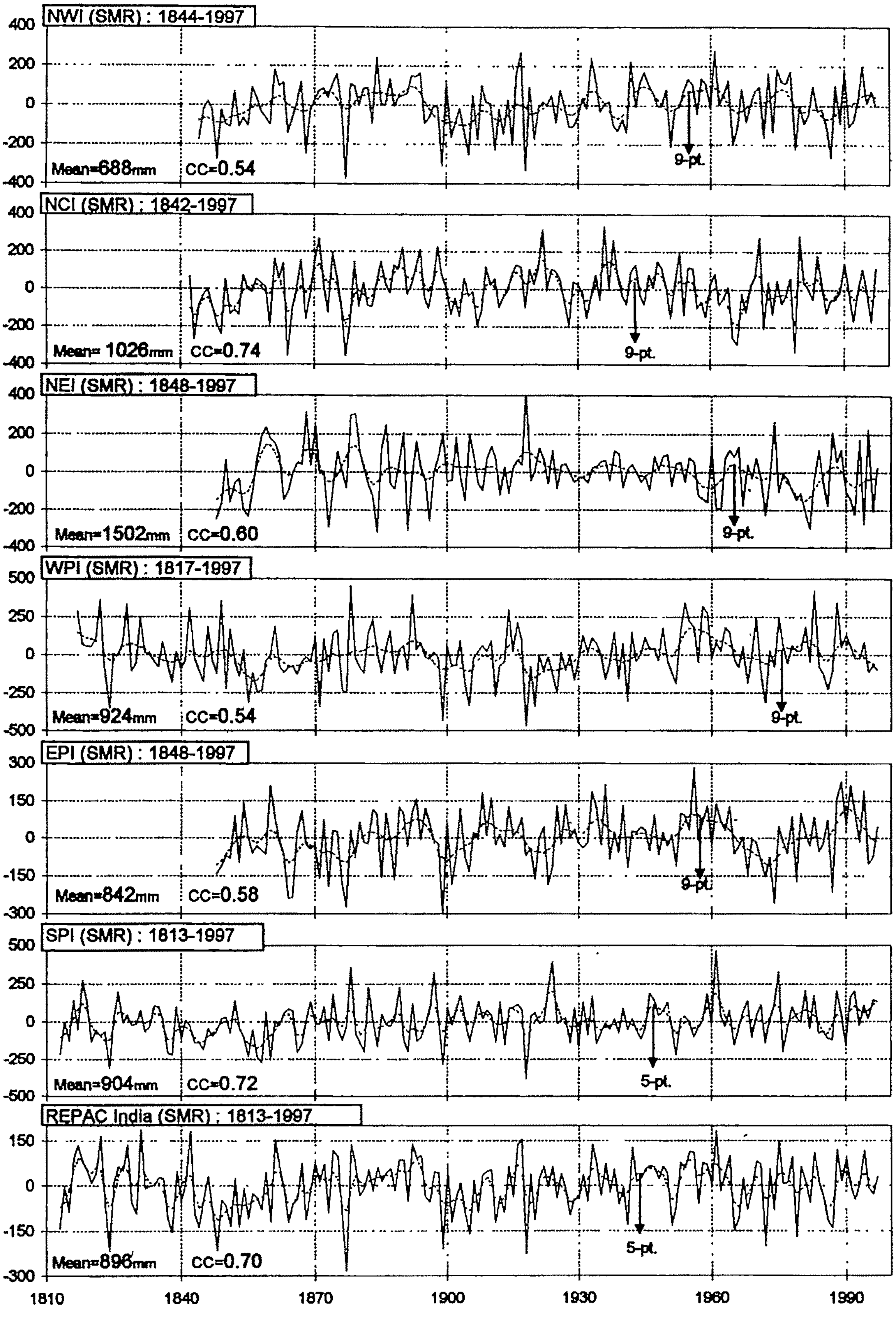

**Fig. 2**: Reconstructed instrumental summer monsoon rainfall series (departure from long term mean in mm) of the REPAC India and its six homogeneous zones (thin curve), and the smoothed version of the corresponding series (explained in Table 3; dotted curve)

### Instrumental Period Post-Monsoon Rainfall Series of the REPAC India and Its Six Zones

The six-zone classification of the country was found satisfactory for effective studies of post-monsoon rainfall (PMR) (Singh and Sontakke 1999). The representative area-averaged PMR series for the period A.D. 1871-1984 for the REPAC India and its six zones were prepared using the October to December total rainfall data of the same 306 stations. The 116 IMD raingauge stations identified for the SMR series provided an excellent set of observations for the reconstruction of the PMR series, including near real-time update, for the six zones and the REPAC India. The backward reconstruction of the PMR series was carried out following the same procedural details as was used for the SMR series (Singh and Sontakke 1999). The NWI series was extended back to A.D. 1844, the NCI to A.D. 1842, the NEI to A.D. 1829, the WPI to A.D. 1841, the EPI to A.D. 1848 and SPI and the REPAC India to A.D. 1813. The reconstruction was most reliable for the SPI where the correlation coefficient always exceeded 0.70. The reconstructed PMR series are seen in Fig. 3.

### Longest Zonal and REPAC India Annual Rainfall Series

Annual rainfall series were prepared to understand the variations in the overall rainfall conditions, irrespective of the season. The series would include the features of the winter and summer rainfall, which collectively contribute nearly 10% to the annual total over the REPAC India, while the SMR contributes 80% and the PMR 10%. The longest annual rainfall series was reconstructed in the same manner as was done for the SMR and PMR series (Singh and Sontakke 1996). The series are presented in Figure 4 for the six zones and the REPAC India.

### Reconstruction of Instrumental Period Seasonal and Annual Rainfall Series of the North Mountainous India

Over north mountainous India (NMI) considerable rainfall occurs during the winter and summer seasons associated with troughs in the westerlies and the western disturbances. The longest rainfall series of the region was reconstructed for each of the four seasons and for the annual total. As stated previously, there are 11 raingauge stations in the region with long period records. For the period A.D. 1901-1970 the representative seasonal and annual rainfall series of the zone was prepared from the arithmetic mean of the 11 raingauges. Backward reconstruction for the period before A.D. 1900, of the individual series was achieved by carrying out the following calculations in the sequential order:

1. of the 11 raingauge stations the gauges for which records for the year 1900 are available were found,
2. the rainfall series for the period A.D. 1901-1970 was prepared from the mean of the available gauges,
3. the linear regression ($Y = a + bX$) of the representative series ($Y$) on the mean series of available gauges ($X$) based on data of A.D. 1901-1970 was estimated,
4. the mean of the available gauges for the year 1900 was substituted in the regression to get an estimate of rainfall amount for the year,
5. the variance of the estimated rainfall amount was inflated commensurate with the representative series (Klein *et al.* 1959) to get the final reconstructed amount for the year 1900,
6. the above processes were repeated taking the next earlier year,
7. the process was continued as long as the correlation between the available gauges mean series and the representative series are significant (at least at 5% level).

For each year of the pre-1901 observation period, the number of available gauges, the number that entered the selection, the highest correlation coefficient achieved and the standard deviation of the estimated series are given in Table 1 for the four seasonal and the annual rainfall series. The SMR and PMR series are extended back to 1944 and winter, summer and annual series back to 1945. The different reconstructed rainfall series for NMI are presented in Fig. 5 and the actual values are given in Table 2.

### Variable Harmonic Analysis (VHA)

Variable (or non-integer) harmonic analysis (VHA) is a modified version of the classical harmonic analysis, developed by Schickedanz and Bowen (1977) for modelling and extrapolation of rainfall time series. The method was adopted mainly for two reasons: (i) it is computationally simple, the results are easy to visualize, and (ii) its application has not been explored much in long-range weather or short term climate predictions. In essence, the method is a generalization of the classical harmonic analysis in which the sine and cosine waveforms are computed for periods which need not be only integer multiples of the fundamental period. In contradistinction with classical harmonic analysis, where the number of harmonics is limited to half the number of data points and all of them close at the end points, in VHA depending upon the wavelength resolution within the fundamental period any number of harmonics can be estimated in which all non-integer harmonics will be open ended. Other notable differences are sine functions and cosine functions of two different harmonics as well as sine and cosine functions of the same harmonic are orthogonal in classical analysis, they are correlated, albeit weakly, in the VHA. Continuity of waveforms beyond the fundamental length makes the

**Table 1**: Some important statistics related to the reconstruction of the longest-possible seasonal and annual rainfall series for the North Mountainous India. The first column gives the available number of gauges, the second gives the number that entered the selection, the third gives the highest CC (*$10^{-4}$) achieved and the fourth gives the S.D. of the estimated series 1901-1970 from the fitted regression (mm). These details against the year 1901 are for updating the particular series

| Year | JF | | | | MAM | | | | JJAS | | | | OND | | | | ANNUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1844 | No Data | | | | No Data | | | | 1 | 1 | 7377 | 139 | 1 | 1 | 8400 | 56 | No data | | | |
| 1845-48 | 1 | 1 | 8195 | 57 | 1 | 1 | 5538 | 50 | 1 | 1 | 7377 | 139 | 1 | 1 | 8400 | 56 | 1 | 1 | 6135 | 131 |
| 1849 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8036 | 151 | 2 | 1 | 8400 | 56 | 2 | 2 | 7392 | 157 |
| 1850 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8036 | 151 | 2 | 1 | 8400 | 56 | 2 | 2 | 7392 | 157 |
| 1851 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8036 | 151 | 2 | 1 | 8400 | 56 | 2 | 2 | 7392 | 157 |
| 1852 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8036 | 151 | 2 | 1 | 8400 | 56 | 2 | 2 | 7392 | 157 |
| 1853 | 3 | 2 | 9393 | 65 | 3 | 2 | 7836 | 70 | 3 | 3 | 9150 | 172 | 3 | 3 | 9190 | 62 | 3 | 3 | 8315 | 177 |
| 1854 | 3 | 2 | 9393 | 65 | 2 | 1 | 7730 | 69 | 3 | 3 | 9150 | 172 | 3 | 3 | 9190 | 62 | 3 | 3 | 8315 | 177 |
| 1855 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8036 | 151 | 1 | 1 | 7312 | 50 | 1 | 1 | 6575 | 140 |
| 1856-59 | 1 | 1 | 7761 | 54 | 1 | 1 | 5198 | 48 | 1 | 1 | 6169 | 116 | 1 | 1 | 7312 | 50 | 1 | 1 | 6575 | 140 |
| 1860 | 1 | 1 | 7761 | 54 | 1 | 1 | 5198 | 48 | 2 | 2 | 8036 | 151 | 1 | 1 | 7312 | 50 | 1 | 1 | 6575 | 140 |
| 1861 | 2 | 2 | 8439 | 58 | 2 | 2 | 5973 | 53 | 2 | 2 | 8869 | 166 | 2 | 2 | 8940 | 60 | 1 | 1 | 6135 | 131 |
| 1862 | 2 | 2 | 9393 | 65 | 2 | 2 | 7836 | 70 | 4 | 4 | 9430 | 177 | 4 | 4 | 9351 | 63 | 2 | 2 | 7745 | 165 |
| 1863 | 4 | 3 | 9427 | 65 | 4 | 2 | 8314 | 74 | 3 | 3 | 9297 | 175 | 4 | 4 | 9351 | 63 | 3 | 3 | 8278 | 176 |
| 1864 | 5 | 3 | 9427 | 65 | 5 | 2 | 8314 | 74 | 5 | 5 | 9722 | 183 | 5 | 4 | 9368 | 63 | 5 | 5 | 8910 | 190 |
| 1865 | 5 | 3 | 9427 | 65 | 5 | 2 | 8314 | 74 | 5 | 5 | 9722 | 183 | 3 | 3 | 9309 | 63 | 5 | 5 | 8910 | 190 |
| 1866 | 5 | 3 | 9427 | 65 | 5 | 2 | 8314 | 74 | 5 | 5 | 9722 | 183 | 5 | 4 | 9368 | 63 | 5 | 5 | 8910 | 190 |
| 1867 | 5 | 3 | 9427 | 65 | 5 | 2 | 8314 | 74 | 5 | 5 | 9722 | 183 | 5 | 4 | 9368 | 63 | 5 | 5 | 8910 | 190 |
| 1868 | 5 | 3 | 9427 | 65 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 5 | 5 | 9604 | 65 | 5 | 5 | 8910 | 190 |
| 1869 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 6 | 5 | 9603 | 65 | 6 | 6 | 9463 | 202 |
| 1870 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 5 | 4 | 9368 | 63 | 6 | 6 | 9463 | 202 |
| 1871 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 6 | 5 | 9603 | 65 | 6 | 6 | 9463 | 202 |
| 1872 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 5 | 5 | 9604 | 65 | 6 | 6 | 9463 | 202 |
| 1873 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 6 | 5 | 9603 | 65 | 6 | 6 | 9463 | 202 |
| 1874 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 3 | 3 | 9096 | 61 | 6 | 6 | 9463 | 202 |
| 1875 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 6 | 6 | 9756 | 183 | 5 | 5 | 9604 | 65 | 6 | 6 | 9463 | 202 |
| 1876 | 5 | 4 | 9570 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 6 | 5 | 9603 | 65 | 7 | 7 | 9480 | 202 |

| Year | JF | | | | MAM | | | | JJAS | | | | OND | | | | ANNUAL | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1877 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 6 | 5 | 9603 | 65 | 7 | 7 | 9480 | 202 |
| 1878 | 6 | 4 | 9562 | 66 | 6 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 4 | 4 | 9351 | 63 | 7 | 7 | 9480 | 202 |
| 1879 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 6 | 5 | 9402 | 63 | 7 | 7 | 9480 | 202 |
| 1880 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1881 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 2 | 2 | 8669 | 58 | 7 | 7 | 9480 | 202 |
| 1882 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 5 | 4 | 9274 | 62 | 7 | 7 | 9480 | 202 |
| 1883 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 6 | 6 | 9605 | 65 | 7 | 7 | 9480 | 202 |
| 1884 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 6 | 5 | 9603 | 65 | 7 | 7 | 9480 | 202 |
| 1885 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1886 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1887 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1888 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1889 | 8 | 7 | 9633 | 67 | 8 | 7 | 9767 | 88 | 8 | 8 | 9833 | 185 | 3 | 3 | 9278 | 62 | 8 | 8 | 9645 | 206 |
| 1890 | 7 | 5 | 9563 | 66 | 7 | 6 | 9664 | 87 | 7 | 7 | 9770 | 183 | 7 | 6 | 9604 | 65 | 7 | 7 | 9480 | 202 |
| 1891 | 8 | 7 | 9633 | 67 | 8 | 7 | 9767 | 88 | 8 | 8 | 9833 | 185 | 9 | 8 | 9740 | 66 | 8 | 8 | 9645 | 206 |
| 1892 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 8 | 7 | 9666 | 65 | 8 | 8 | 9645 | 206 |
| 1893 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 8 | 7 | 9620 | 65 | 9 | 9 | 9689 | 207 |
| 1894 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 9 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1895 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 9 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1896 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 9 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1897 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 8 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1898 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 9 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1899 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 8 | 8 | 9740 | 66 | 9 | 9 | 9689 | 207 |
| 1900 | 9 | 7 | 9761 | 67 | 9 | 8 | 9793 | 88 | 9 | 9 | 9845 | 185 | 8 | 8 | 9680 | 65 | 9 | 9 | 9689 | 207 |
| 1971 | 11 | 10 | 9999 | 69 | 11 | 10 | 9998 | 90 | 11 | 10 | 9999 | 188 | 11 | 10 | 9998 | 67 | 11 | 10 | 9998 | 213 |

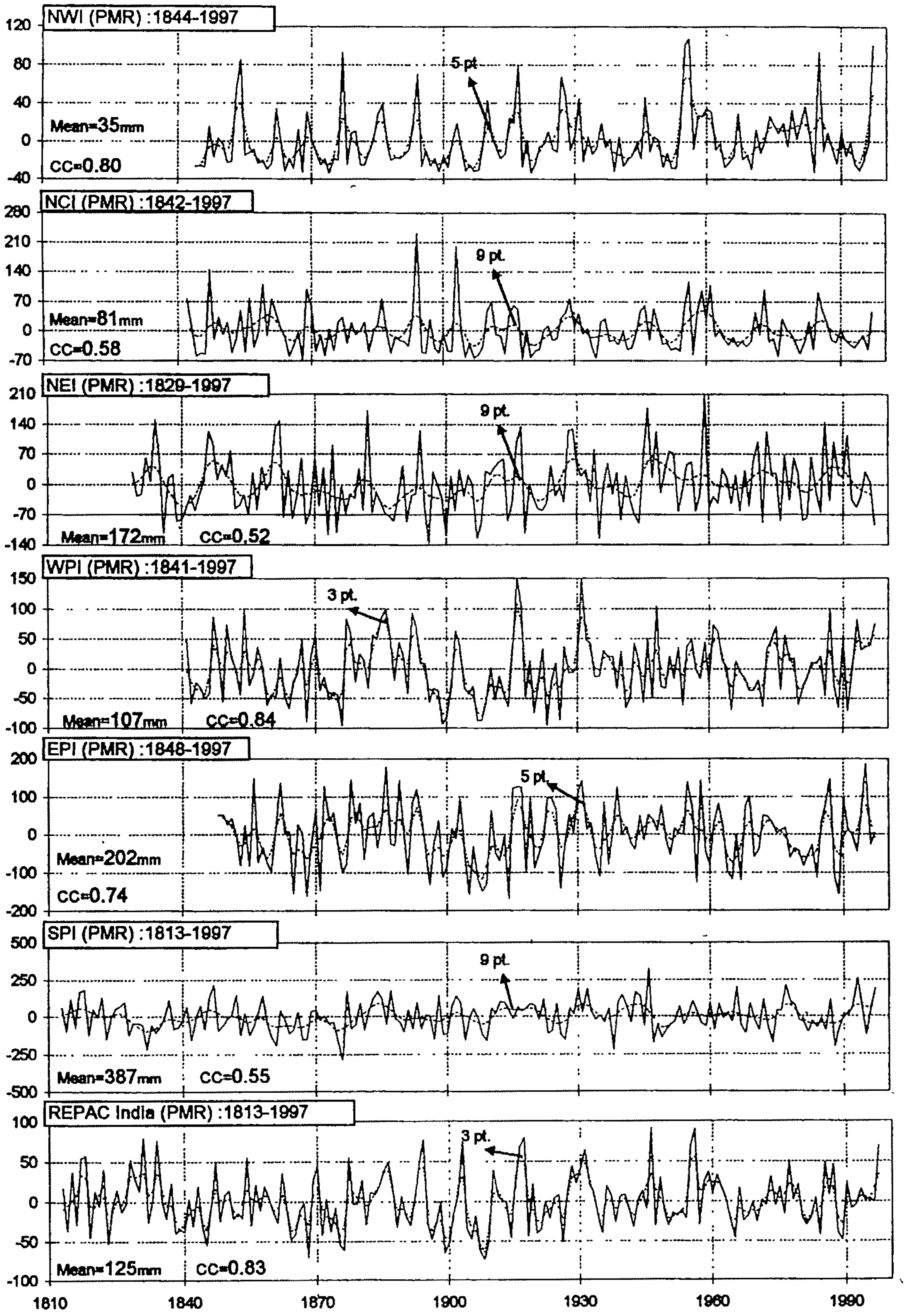

**Fig. 3**: Same as in Table 2, but for the PMR series

**Table 2**: Reconstructed seasonal and annual rainfall (in mm) for the North Mountainous India Zone

| Year | JF | MAM | JJAS | OND | ANN | Year | JF | MAM | JJAS | OND | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1844 | 9999.9 | 9999.9 | 981.4 | 51.4 | 9999.9 | 1921 | 136.4 | 76.1 | 1021.3 | 153.1 | 1387.0 |
| 1845 | 42.7 | 208.9 | 740.6 | 55.6 | 1123.2 | 1922 | 138.7 | 102.9 | 1251.3 | 62.9 | 1556.0 |
| 1846 | 78.1 | 120.7 | 769.2 | 66.1 | 1152.2 | 1923 | 281.2 | 180.8 | 826.0 | 151.9 | 1440.0 |
| 1847 | 74.2 | 317.9 | 984.4 | 105.4 | 1466.6 | 1924 | 179.2 | 178.7 | 1109.5 | 123.8 | 1591.4 |
| 1848 | 211.9 | 267.1 | 621.1 | 49.6 | 1083.4 | 1925 | 103.2 | 203.1 | 978.6 | 117.0 | 1402.1 |
| 1849 | 252.7 | 137.6 | 971.9 | 54.9 | 1445.6 | 1926 | 59.7 | 462.3 | 931.5 | 44.8 | 1498.4 |
| 1850 | 234.1 | 395.9 | 442.3 | 25.3 | 982.5 | 1927 | 151.1 | 231.5 | 1055.3 | 111.8 | 1549.9 |
| 1851 | 192.7 | 132.6 | 822.5 | 29.9 | 1229.4 | 1928 | 264.2 | 235.4 | 758.1 | 192.7 | 1450.6 |
| 1852 | 109.7 | 305.3 | 1265.4 | 71.4 | 1760.8 | 1929 | 102.1 | 130.8 | 873.8 | 234.8 | 1341.6 |
| 1853 | 71.9 | 139.9 | 1118.5 | 205.3 | 1624.0 | 1930 | 155.3 | 367.6 | 843.2 | 42.7 | 1408.9 |
| 1854 | 252.6 | 370.5 | 737.3 | 112.6 | 1315.2 | 1931 | 140.2 | 160.3 | 807.0 | 91.8 | 1199.4 |
| 1855 | 111.6 | 204.5 | 777.2 | 73.8 | 1305.1 | 1932 | 71.4 | 139.7 | 1083.6 | 72.3 | 1367.2 |
| 1856 | 146.5 | 358.0 | 792.5 | 130.2 | 1426.6 | 1933 | 145.0 | 291.8 | 1086.3 | 120.4 | 1643.6 |
| 1857 | 158.5 | 407.6 | 1163.1 | 68.0 | 1695.6 | 1934 | 94.9 | 167.6 | 1102.3 | 70.4 | 1435.3 |
| 1858 | 218.6 | 290.3 | 1165.5 | 76.9 | 1682.4 | 1935 | 196.8 | 283.9 | 840.8 | 72.7 | 1394.3 |
| 1859 | 84.1 | 157.2 | 1056.4 | 84.7 | 1400.1 | 1936 | 122.9 | 275.6 | 1168.3 | 128.0 | 1694.9 |
| 1860 | 133.0 | 397.0 | 1268.6 | 121.3 | 1768.8 | 1937 | 183.6 | 204.8 | 970.9 | 128.2 | 1487.7 |
| 1861 | 57.4 | 263.8 | 588.4 | 57.8 | 975.5 | 1938 | 275.8 | 137.8 | 966.8 | 26.5 | 1407.1 |
| 1862 | 225.4 | 195.3 | 908.9 | 79.8 | 1335.2 | 1939 | 147.0 | 200.6 | 847.1 | 41.0 | 1235.9 |
| 1863 | 105.0 | 278.1 | 840.4 | 30.7 | 1267.9 | 1940 | 164.6 | 178.2 | 817.9 | 36.1 | 1196.9 |
| 1864 | 131.4 | 74.4 | 1044.7 | 103.1 | 1467.8 | 1941 | 87.6 | 109.9 | 767.7 | 96.6 | 1062.0 |
| 1865 | 170.8 | 97.1 | 1252.6 | 68.7 | 1670.7 | 1942 | 249.9 | 243.7 | 1137.9 | 108.0 | 1739.5 |
| 1866 | 255.3 | 184.5 | 802.0 | 165.6 | 1328.4 | 1943 | 173.1 | 252.1 | 1095.7 | 25.6 | 1546.6 |
| 1867 | 177.8 | 167.7 | 1043.2 | 138.6 | 1516.2 | 1944 | 201.7 | 263.9 | 812.0 | 115.0 | 1392.7 |
| 1868 | 78.9 | 209.1 | 934.3 | 132.1 | 1362.2 | 1945 | 149.6 | 296.7 | 1025.8 | 83.7 | 1555.9 |
| 1869 | 55.3 | 453.0 | 878.6 | 58.8 | 1447.5 | 1946 | 90.9 | 202.2 | 886.3 | 176.3 | 1355.9 |
| 1870 | 149.0 | 226.4 | 1082.5 | 153.4 | 1611.0 | 1947 | 104.4 | 117.1 | 935.7 | 108.9 | 1266.2 |
| 1871 | 231.8 | 255.5 | 733.8 | 137.6 | 1313.9 | 1948 | 161.0 | 341.8 | 996.7 | 89.9 | 1589.6 |
| 1872 | 101.1 | 140.5 | 916.4 | 212.6 | 1374.8 | 1949 | 187.9 | 218.1 | 924.5 | 37.4 | 1368.0 |
| 1873 | 160.6 | 337.5 | 849.6 | 59.5 | 1373.6 | 1950 | 233.7 | 251.1 | 1240.2 | 7.8 | 1733.0 |
| 1874 | 155.0 | 164.6 | 791.8 | 105.4 | 1203.8 | 1951 | 132.4 | 266.9 | 791.2 | 101.2 | 1291.8 |
| 1875 | 53.7 | 118.4 | 1083.6 | 73.5 | 1399.6 | 1952 | 130.4 | 233.0 | 741.8 | 59.1 | 1164.3 |
| 1876 | 166.0 | 320.1 | 1086.5 | 120.0 | 1683.5 | 1953 | 153.6 | 177.8 | 992.7 | 57.5 | 1381.8 |
| 1877 | 125.0 | 183.5 | 1123.3 | 75.1 | 1531.6 | 1954 | 366.6 | 105.1 | 1151.8 | 117.1 | 1740.7 |
| 1878 | 201.7 | 275.7 | 851.1 | 72.8 | 1367.2 | 1955 | 104.6 | 288.8 | 1020.6 | 378.3 | 1792.5 |
| 1879 | 113.0 | 263.0 | 1157.8 | 131.6 | 1660.7 | 1956 | 98.0 | 274.3 | 989.1 | 343.5 | 1705.0 |
| 1880 | 221.3 | 218.6 | 1043.6 | 148.8 | 1586.3 | 1957 | 169.5 | 345.0 | 886.3 | 199.9 | 1600.8 |
| 1881 | 268.9 | 137.8 | 965.2 | 31.3 | 1391.8 | 1958 | 75.4 | 153.6 | 1200.7 | 155.7 | 1585.5 |
| 1882 | 143.9 | 215.5 | 898.4 | 74.7 | 1318.0 | 1959 | 240.0 | 173.5 | 1167.1 | 163.9 | 1744.5 |

| Year | JF | MAM | JJAS | OND | ANN |
|---|---|---|---|---|---|
| 1883 | 155.6 | 201.0 | 845.7 | 38.5 | 1277.6 |
| 1884 | 92.9 | 121.1 | 794.2 | 94.9 | 1137.9 |
| 1885 | 224.3 | 254.4 | 1145.1 | 76.2 | 1714.4 |
| 1886 | 188.3 | 270.1 | 1194.1 | 17.3 | 1684.9 |
| 1887 | 191.2 | 245.7 | 821.7 | 111.7 | 1332.5 |
| 1888 | 181.0 | 280.7 | 1056.9 | 100.7 | 1618.6 |
| 1889 | 76.0 | 218.8 | 889.7 | 184.6 | 1373.2 |
| 1890 | 109.8 | 134.4 | 870.4 | 72.9 | 1221.6 |
| 1891 | 186.1 | 307.0 | 910.7 | 123.2 | 1492.1 |
| 1892 | 185.1 | 214.3 | 933.5 | 43.0 | 1387.3 |
| 1893 | 194.0 | 268.3 | 1217.1 | 10.9 | 1715.7 |
| 1894 | 148.1 | 250.8 | 802.4 | 114.2 | 1290.3 |
| 1895 | 103.5 | 196.6 | 724.3 | 24.3 | 1065.3 |
| 1896 | 171.6 | 179.3 | 963.5 | 52.7 | 1372.1 |
| 1897 | 345.5 | 115.8 | 1192.0 | 115.7 | 1780.4 |
| 1898 | 93.7 | 263.9 | 1006.9 | 364.2 | 1739.4 |
| 1899 | 87.7 | 273.6 | 964.2 | 339.4 | 1688.5 |
| 1900 | 185.5 | 389.1 | 883.8 | 219.2 | 1643.4 |
| 1901 | 242.1 | 205.0 | 878.6 | 38.8 | 1364.6 |
| 1902 | 15.3 | 317.1 | 723.3 | 42.7 | 1098.5 |
| 1903 | 86.3 | 247.5 | 739.6 | 72.2 | 1145.8 |
| 1904 | 83.9 | 239.7 | 900.6 | 131.4 | 1355.7 |
| 1905 | 236.6 | 249.1 | 648.7 | 47.5 | 1182.1 |
| 1906 | 213.8 | 147.5 | 1063.3 | 35.7 | 1460.4 |
| 1907 | 266.2 | 417.2 | 486.1 | 16.1 | 1185.7 |
| 1908 | 120.0 | 341.3 | 864.4 | 45.7 | 1371.6 |
| 1909 | 163.8 | 140.7 | 1096.1 | 92.4 | 1493.1 |
| 1910 | 131.9 | 150.8 | 1146.7 | 151.0 | 1580.5 |
| 1911 | 294.6 | 327.0 | 698.9 | 131.8 | 1452.5 |
| 1912 | 137.7 | 226.1 | 831.1 | 55.8 | 1250.8 |
| 1913 | 161.2 | 254.5 | 696.9 | 89.2 | 1201.9 |
| 1914 | 187.9 | 399.7 | 1214.7 | 153.9 | 1956.4 |
| 1915 | 177.0 | 298.9 | 904.1 | 44.2 | 1424.3 |
| 1916 | 71.5 | 140.4 | 1055.1 | 74.4 | 1341.5 |
| 1917 | 56.3 | 441.9 | 1405.3 | 185.2 | 2088.8 |
| 1918 | 29.2 | 471.0 | 675.3 | 74.8 | 1250.3 |
| 1919 | 230.1 | 217.0 | 1070.9 | 85.1 | 1603.1 |
| 1920 | 110.3 | 301.4 | 797.2 | 22.3 | 1231.4 |
| 1960 | 68.8 | 168.9 | 859.8 | 91.8 | 1189.4 |
| 1961 | 245.5 | 202.6 | 1195.9 | 199.0 | 1843.1 |
| 1962 | 144.4 | 224.3 | 1031.8 | 101.7 | 1502.3 |
| 1963 | 47.4 | 300.8 | 1076.7 | 102.0 | 1527.1 |
| 1964 | 123.9 | 294.3 | 1021.4 | 52.2 | 1491.9 |
| 1965 | 169.6 | 403.5 | 549.8 | 59.8 | 1182.8 |
| 1966 | 125.9 | 240.3 | 1186.2 | 85.9 | 1638.4 |
| 1967 | 64.1 | 211.1 | 1498.9 | 149.4 | 1923.5 |
| 1968 | 235.6 | 150.2 | 786.8 | 85.6 | 1258.4 |
| 1969 | 107.7 | 316.8 | 954.7 | 14.5 | 1393.7 |
| 1970 | 108.6 | 103.3 | 1002.0 | 28.0 | 1242.1 |
| 1971 | 127.7 | 142.1 | 1112.2 | 95.9 | 1477.9 |
| 1972 | 158.3 | 162.2 | 905.0 | 108.3 | 1333.3 |
| 1973 | 198.1 | 179.5 | 1126.6 | 78.7 | 1583.2 |
| 1974 | 129.3 | 122.4 | 732.8 | 95.6 | 1079.0 |
| 1975 | 203.4 | 247.9 | 1107.0 | 41.7 | 1601.0 |
| 1976 | 189.4 | 201.9 | 930.5 | 26.1 | 1348.2 |
| 1977 | 216.1 | 200.7 | 1216.2 | 99.4 | 1732.9 |
| 1978 | 108.3 | 263.6 | 1203.6 | 75.5 | 1652.0 |
| 1979 | 154.3 | 285.7 | 610.5 | 84.0 | 1134.1 |
| 1980 | 124.7 | 126.5 | 1008.2 | 80.8 | 1339.9 |
| 1981 | 151.4 | 261.7 | 822.1 | 60.3 | 1295.6 |
| 1982 | 154.2 | 372.3 | 638.1 | 105.0 | 1269.6 |
| 1983 | 136.8 | 409.8 | 869.7 | 58.9 | 1476.4 |
| 1984 | 130.1 | 128.9 | 869.2 | 59.6 | 1187.4 |
| 1985 | 78.0 | 139.0 | 915.3 | 224.5 | 1355.5 |
| 1986 | 81.0 | 253.3 | 907.2 | 216.7 | 1457.6 |
| 1987 | 123.7 | 306.6 | 659.4 | 75.3 | 1165.0 |
| 1988 | 128.9 | 239.1 | 1153.2 | 92.5 | 1614.4 |
| 1989 | 125.4 | 163.7 | 881.9 | 108.6 | 1279.1 |
| 1990 | 193.0 | 282.8 | 918.8 | 133.2 | 1527.8 |
| 1991 | 131.0 | 235.6 | 672.6 | 37.2 | 1076.3 |
| 1992 | 223.8 | 199.8 | 812.7 | 33.9 | 1270.1 |
| 1993 | 185.3 | 261.9 | 970.7 | 23.8 | 1442.1 |
| 1994 | 166.0 | 199.7 | 1017.7 | 75.9 | 1459.3 |
| 1995 | 217.5 | 162.6 | 1024.2 | 52.3 | 1456.5 |
| 1996 | 199.3 | 232.7 | 1019.7 | 67.6 | 1519.9 |
| 1997 | 87.6 | 286.2 | 836.9 | 220.1 | 1430.5 |

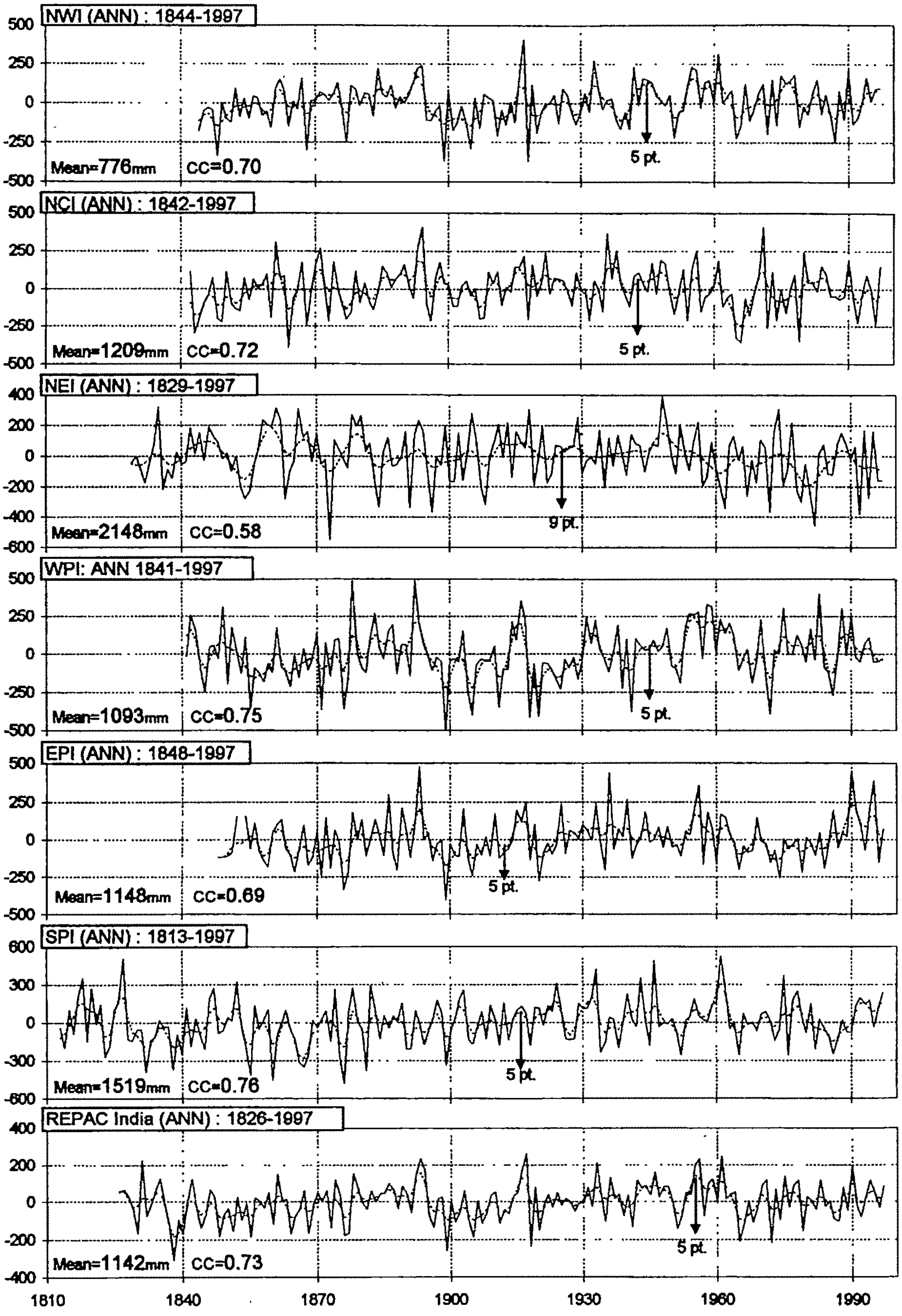

Fig. 4: Same as in Table 2, but for the annual rainfall series

VHA a potential tool for extrapolation. The sine coefficient (a) and cosine coefficient (b) of the VHA are defined by the expressions:

$$X_j = \overline{X} + \sum_{l=1}^{k}[a_l \sin(2\pi lj/P) + b_l \cos(2\pi lj/P)] \quad \ldots (1)$$

$$b'_p = \left(\frac{2}{N}\right)\sum_{j=1}^{N} X_j \cos(2\pi j / p) \quad \ldots\ldots. (2)$$

$$b_2 = \left(\frac{1}{N}\right)\sum_{j=1}^{N} X_j \cos(2\pi j / p) \quad \ldots\ldots. (3)$$

$$0 < p \le P$$

where p is the wavelength of the variable harmonic numbered as i, i is a counter for the number of waveforms that are calculated. The wavelength p and the fundamental period P are related as follows:

$$p = p - \beta(i - 1) \quad \ldots\ldots (4)$$

where is the resolution of wavelength for the estimation of harmonics. The wavelength p of the harmonic with i equal to one will be equal to the fundamental period P, with i equal to two p will be equal to $P - \beta$ , with i equal to three p will be equal to $P - 2\beta$ and so on.

The selected harmonics are combined using the following expression to generate a series $[X_j]$,

$$X_j = \overline{X} + \sum_{l=1}^{k}[a_l \sin(2\pi lj / P) + b_l \cos(2\pi lj / P)] \ldots (5)$$

where k denotes the selected variable harmonics. A linear regression of $[x_j]$ on $[X_j]$ is estimated to get an estimate of $[x_j]$ from the linear combination of the selected harmonics.

### VHA of the Longest Instrumental Rainfall Series and 10-yr Extrapolation

An attempt has been made to make a prediction for a 10 year period by modelling and extrapolating the longest instrumental rainfall series using VHA. One-step-ahead prediction considering the inter-annual series was not found satisfactory. The present attempt is to predict the future rainfall trend in the slow varying mode. Therefore, a smoothed version of different series is subjected to VHA and extrapolated. The 3-, 5- and 9-point low pass filters were tried one by one, and the smoothing was finalized when the best result between smooth and extrapolated values for 10-year independent period (A.D. 1988-1997) was obtained. The step by step procedural details in order to model and extrapolate the SMR series of northwest India (the long term mean is removed from each term of the series and then considered in the analysis) are:

1. The NWI SMR series of the period A.D. 1844-1997 was smoothened using 3-point filter with weights 0.25, 0.50, 0.25 (filter weights are folded to get smooth values at the end points),
2. The smoothened series of the period A.D. 1844-1987 was considered with 10 years data (A.D. 1987-1997) reserved for independent verification,
3. Zero was substituted at each term of the period A.D. 1988-1997 and they were augmented with the smooth series of the period A.D. 1844-1987,
4. The entire series (A.D. 1844-1997), that is smooth series of the period A.D. 1844-1987 plus the series A.D. 1988-1997 filled with zero was subjected to the VHA using a wavelength resolution of 0.1 year,
5. An optimum subset of about 5 to 6 wavelengths whose linear combination shows correlation of ~0.85 with the smooth series (Singh, 1994) was selected objectively. In this process preference was given to select longer wavelengths (longer than 5 or 10-year),
6. The least-squares linear regression of the smooth series on the mean series of the selected wavelengths was estimated,
7. The extrapolated values for the 10-yr period 1988-1997 were compared with the corresponding smooth values,
8. If a satisfactory result is not obtained, the series was smoothened using 5-point low pass filter with weights 0.06, 0.25, 0.38, 0.25, 0.06 or 9-point filter with weights 0.02, 0.05, 0.12, 0.20, 0.22, 0.20, 0.12, 0.05, 0.02 (filter weights are folded to get smooth values at the end points) (WMO 1966) and the above calculations were repeated sequentially.

In this process sometimes better results were obtained when a shorter period of data was used in the analysis rather than the whole reconstructed series. Sometimes we have to assign a threshold for the correlation coefficient other than ~0.85 to seek best result. For the REPAC India and its six zones the results are presented in Figure 6 for SMR, in Figure 7 for PMR and in Figure 8 for the annual rainfall. For the seasonal and annual rainfall of the NMI these results are presented in Figure 9. Satisfactory results were not obtained for the SMR of NWI, NEI and SPI, for the PMR of NWI, NCI, NEI, EPI and REPAC India, for the annual rainfall of NCI, WPI and REPAC India and the different seasonal rainfall of the NMI. But it can be seen that in the majority of cases that for shorter lead-time, such as up to 3 or 4 steps, the smooth and predicted values were closely parallel. They start drifting away for longer lead-times. Though there are large differences, it is interesting to note that in most of the cases there is a close parallelism between the smooth and predicted values. It appears we have to improve upon the present approach on two counts:

**Table 3**: Details of the modeling of the reconstructed seasonal and annual rainfall series. Shown are: the low pass filter applied; the percentage variance retained (PVR); the wavelengths of the variable harmonics that were considered in the selection; the wavelength that entered the selection (in order); and the CC achieved between the smoothed series and the selected wavelengths

| | **PVR** | **Wave-lengths (≥ 10 yrs)** | **Wavelengths selected (years)** | **CC achieved SMR** |
|---|---|---|---|---|
| NWI | 29 | 10 | 98, 15.6, 12.5, 18.9 | .85 |
| NCI | 55 | 10 | 28.9, 156, 16.3, 12.5, 21.6, 9.0, 6.4, 56.3, 5.4 | .81 |
| NEI | 36 | 10 | 150.0, 18.3, 44.0, 10.7, 21.2, 55.7, 117, 10.1, 15.1 | .85 |
| WPI | 29 | 10 | 70.1, 22.6, 181.0, 16.2, 35.9 | .84 |
| EPI | 33 | 10 | 24.5, 55.3, 150.0, 17.4, 33.9 | .77 |
| SPI | 52 | 5 | 185.0, 11.9, 7.6, 18.4, 8.7, 6.5, 45.8, 91.0, 9.1, 10.7, 15.9 | .81 |
| RPCI | 49 | 5 | 65.3, 12.8, 10.6, 7.5, 185.0, 30.4, 6.7, 17.2, 9.1, 23.1, 14.6 | .82PMR |
| NWI | 64 | 5 | 32.9, 7.7, 15.0, 21.0, 154.0, 24.3, 8.1, 10.2, 13.1, 8.7 | .84 |
| NCI | 33 | 10 | 14.2, 11.1, 15.8, 33.4, 17.7, 13.0, 23.9, 103.5 | .83 |
| NEI | 28 | 10 | 133.7, 15.2, 10.4, 19.0, 16.8, 12.9 | .85 |
| WPI | 71 | 5 | 15.4, 7.6, 36.8, 13.7, 49.1, 11.7, 23.5, 6.5, 78.4, 9.0, 8.0 | .79 |
| EPI | 55 | 5 | 7.6, 38.1, 13.9, 57.3, 6.3, 29.8, 9.6, 7.2, 103.8 | .84 |
| SPI | 32 | 10 | 15.3, 138.0, 28.9, 12.1, 46.4, 11.1 | .78 |
| RPCI | 72 | 5 | 14.7, 7.7, 35.8, 8.8, 23.0, 10.5, 146.3, 13.1, 6.3, 49.1, 7.3, | .79Annual Rainfall |
| NWI | 49 | 5 | 77.3, 10.2, 17.0, 7.5, 31.5, 12.9, 50.7, 21.9, 6.8, 9.0, 8.3 | .84 |
| NCI | 51 | 5 | 29.8, 11.1, 123.5, 60.1, 12.4, 16.7, 8.3, 21.9, 6.4, 5.4, 7.6 | .85 |
| NEI | 33 | 10 | 76.6, 18.1, 11.7, 21.4, 16.3, 10.8, 169.0, 40.3 | .85 |
| WPI | 56 | 5 | 22.4, 62.7, 157.0, 10.6, 7.5, 8.1, 15.9, 13.2, 6.7 | .84 |
| EPI | 48 | 5 | 58.5, 24.8, 7.7, 108.4, 10.6, 34.6, 12.8, 5.9, 19.7 | .80 |
| SPI | 57 | 5 | 162.6, 7.5, 36.3, 8.9, 19.0, 14.3, 30.4, 11.9, 8.5, 15.5, 26.4 | .80 |
| RPCI | 53 | 5 | 66.1, 7.5, 31.8, 172.0, 14.3, 12.5, 21.8, 6.8, 10.2, 11.2, 16.5 | .84NMI |
| JF | 28 | 10 | 14.1, 55.6, 15.6, 23.0, 17.4, 29.7, 20.2 | .84 |
| MAM | 64 | 10 | 15.5, 51.5, 18.1, 74.5, 12.0, 33.1, 158.2, 13.1, 26.4, 11.0, 22.3 | .85 |
| SMR | 53 | 5 | 5.7, 45.6, 19.6, 9.9, 6.4, 8.4, 27.2, 78.5, 9.0, 11.3, 36.5 | .82 |
| PMR | 53 | 10 | 29.6, 14.6, 20.6, 11.5, 61.4, 48.3 | .84 |
| ANN | 28 | 5 | 9.8, 20.1, 45.5, 5.7, 11.3, 32.0, 66.7, 6.4, 14.9 | .84 |

(i) first, to choose a suitable filter retaining a greater portion of the actual series variance so that prediction of long period fluctuations is useful for practical purposes; and (ii) secondly, to improve upon the estimation procedure of the coefficients of the variable harmonics by withdrawing the assumption of normality between sine waveform and cosine waveform between the harmonics and within the harmonics.

### Prediction for 10-yr Future Period

For the prediction of the rainfall fluctuations over 10-yr period (A.D. 1998-2007), the smooth series up to 1997 plus the series 1998-2007 filled with zero is subjected to the VHA as described in the preceding section. But the type of filter, the number of selected harmonics and the threshold limit of CC between smooth series and the mean series of selected harmonics used in the preceding calcula-

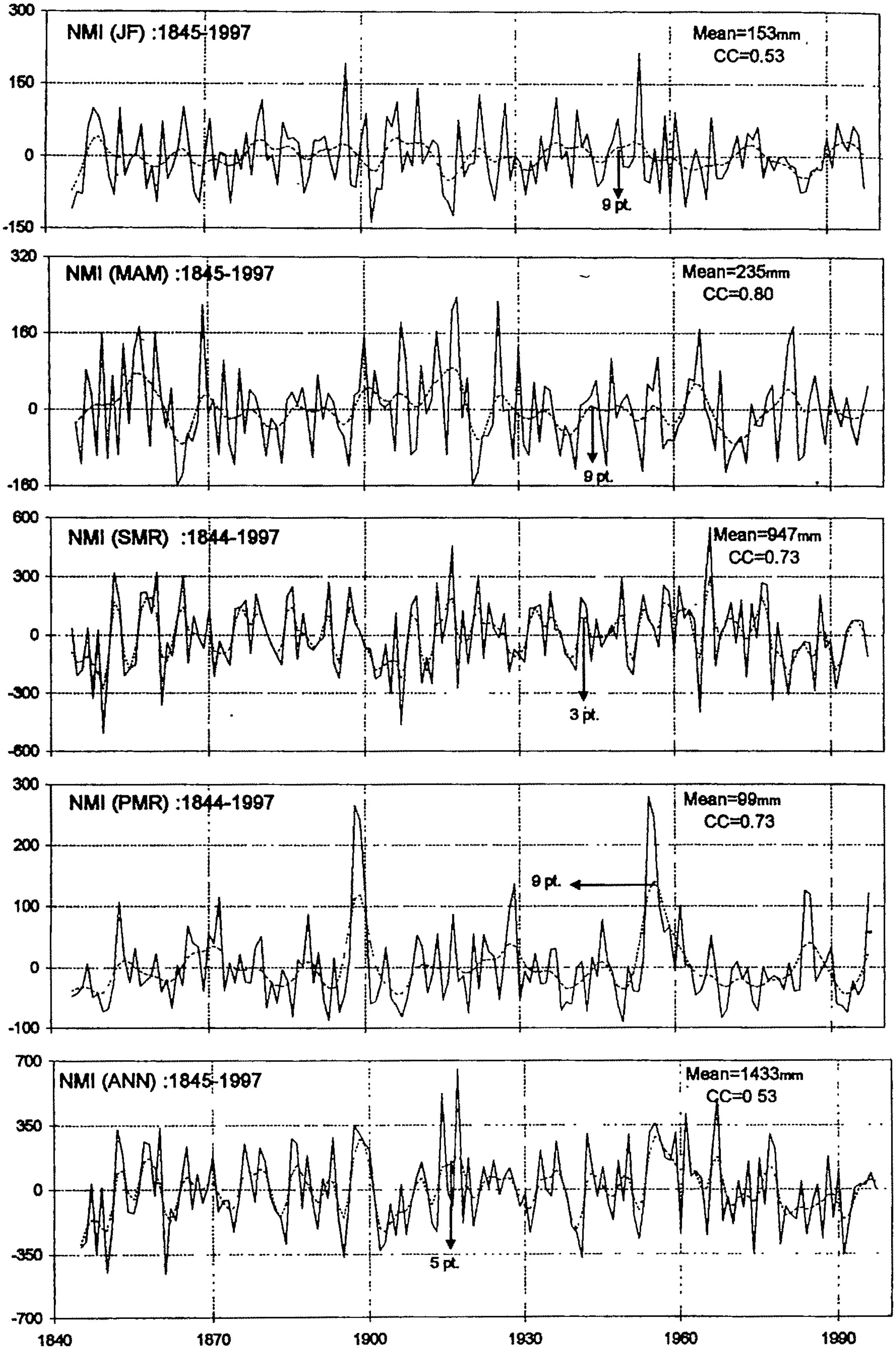

**Fig. 5**: As in Table 2, but for the seasonal and annual rainfall series of the NMI

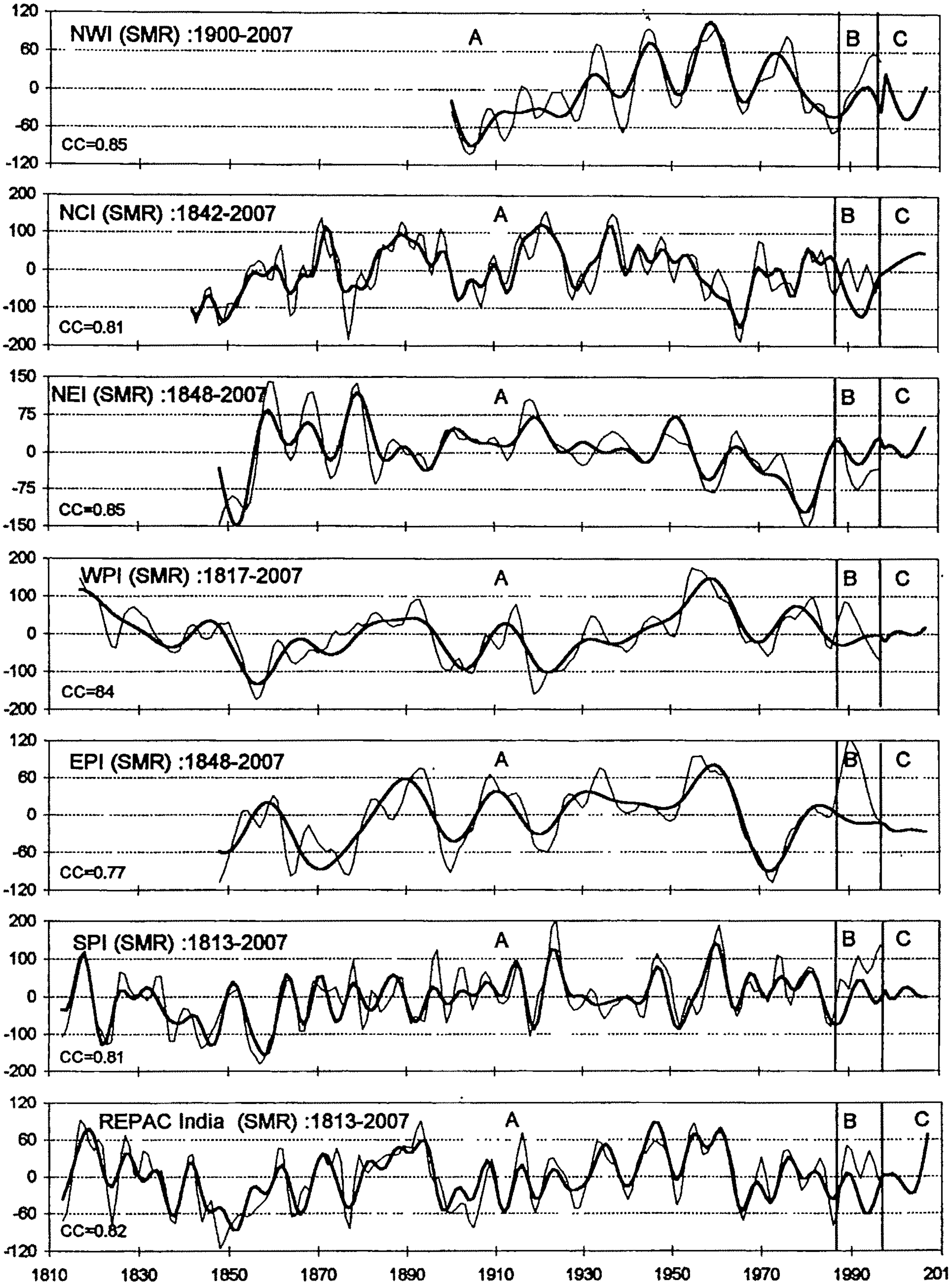

Fig. 6: Smoothed (thin curve) and estimated (thick curve) SMR series of the REPAC India and its six zones. A indicates the dependent sample period (from the start of the series upto 1987); B indicates the independent sample period (1988-1997); and C indicates the prediction for a 10-yr future period (1998-2007)

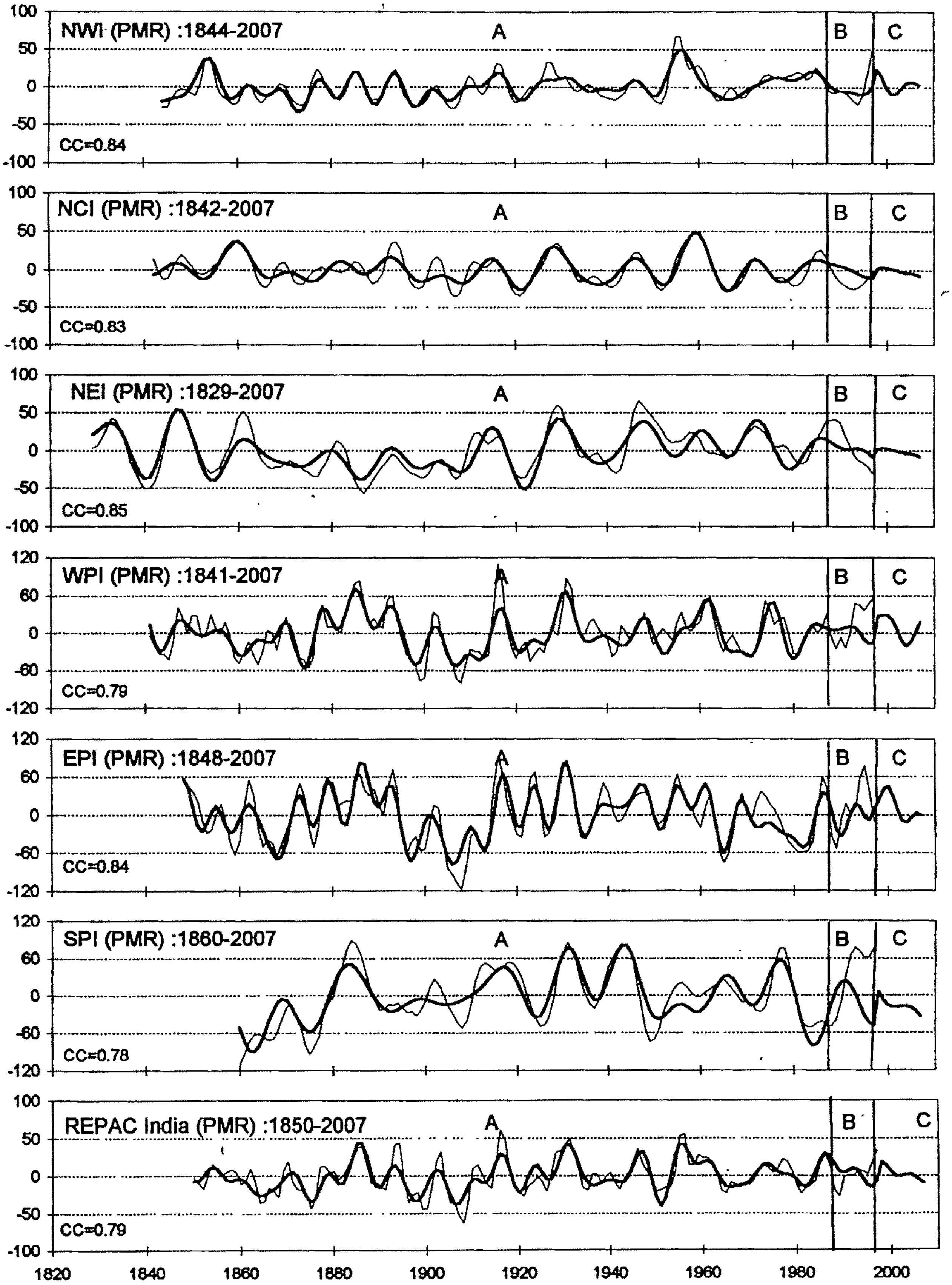

Fig. 7: As in Figure 6; but for the PMR series

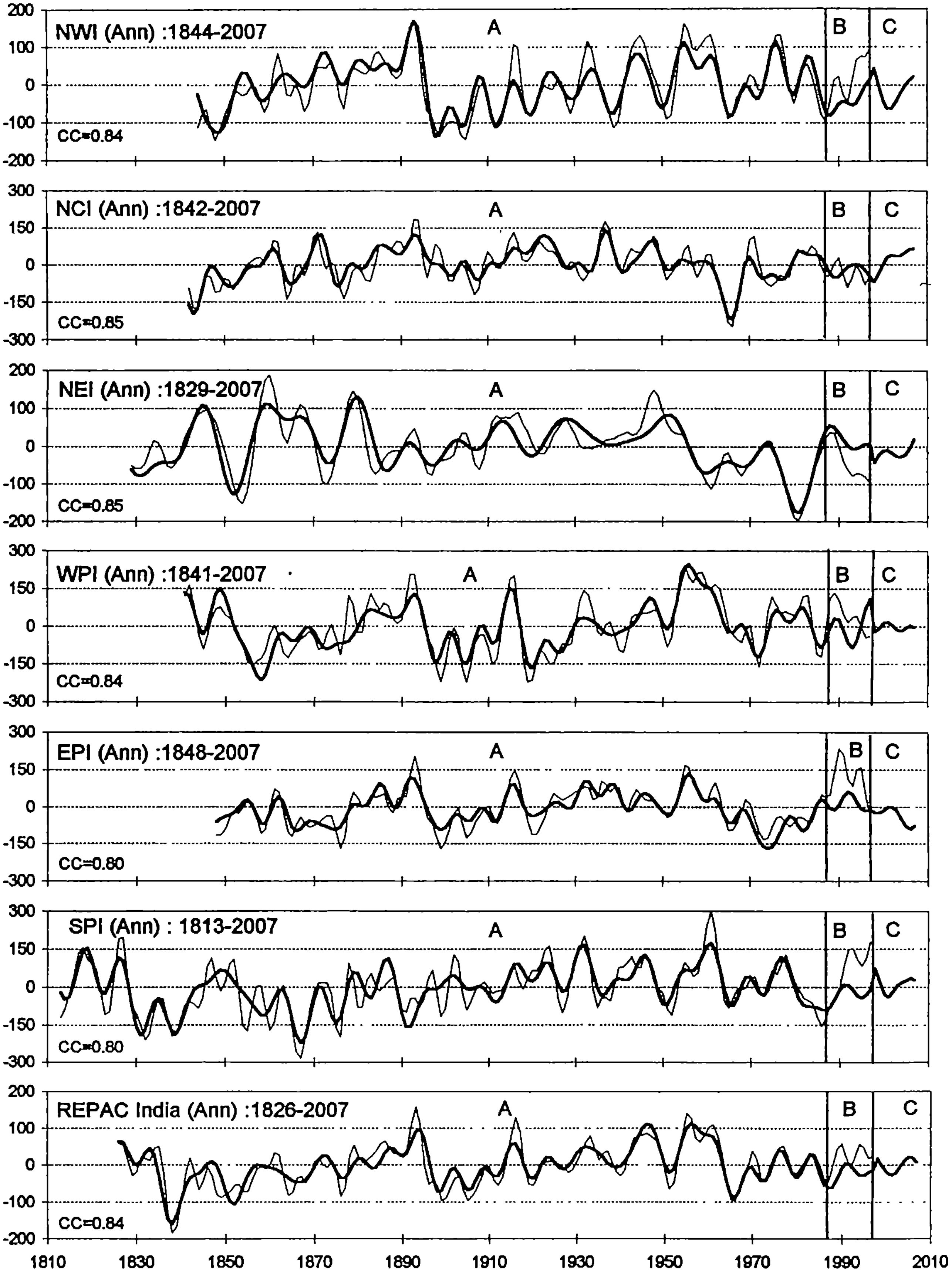

Fig. 8: As in Figure 6; but for the annual rainfall series

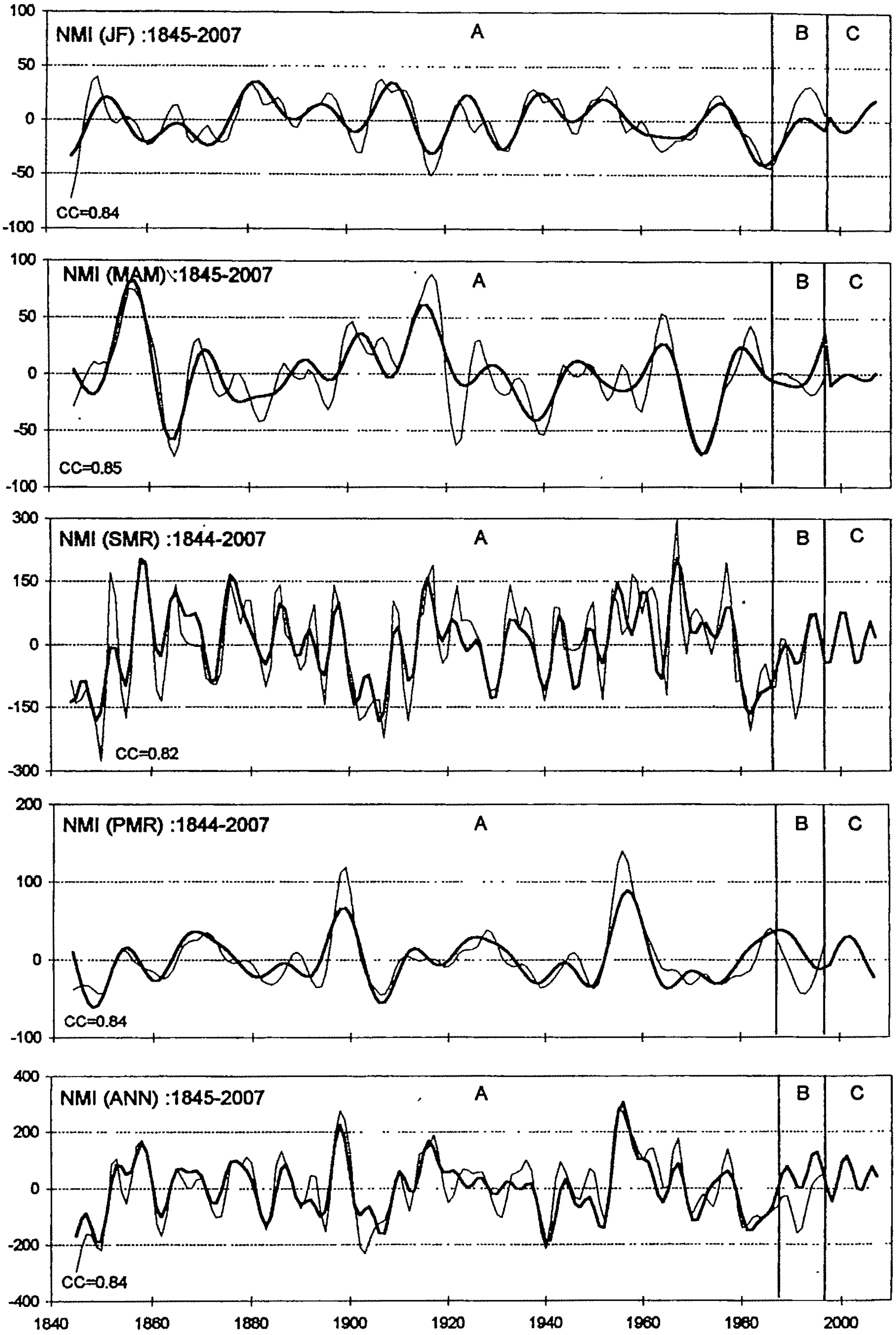

**Fig. 9**: As in Figure 6; but for the seasonal and annual rainfall series of the NMI

tions are retained. The results are presented along with the respective series in Figures 6-9. Broadly speaking, the rainfall pattern over the 10-yr future period is likely to fluctuate around the long term mean.

### Concluding Remarks

Keeping in view the limitations of the present approach to long period prediction as well as the results of comparison between predicted and smooth values over a 10-yr period (1988-1997) do not permit us to draw any other inference than that the rainfall fluctuation across the country is likely to be around the long-term mean.

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# Late Quaternary Environmental Changes and Human Occupation of the Tibetan Plateau

Frank Lehmkuhl, Jürgen Böhner and Frank Haselein

Geographisches Institut der Universität Göttingen,
Goldschmidtstr. 5, D-37077
Göttingen,
Germany

## Abstract

Investigations in the eastern and central part of the Tibetan Plateau have focussed on the environmental changes of the last glacial-interglacial cycle. The reconstruction of the spatial distribution and timing of Pleistocene glaciations and lake level changes is of particular interest. Our research is in agreement with that of others and concludes that duing cold phases of the last glaciation, the glaciers were at their maximum extent and periglacial features including large alluvial fans were forming. These periods alternate with periods of high lake levels in most areas of Central Asia. This can be proved by detailed investigations of the morphological sequences at the lake Nam Co. In areas where the Pleistocene glaciations were less extensive, alluvial fans and traces of higher lake levels can be found. Higher lake levels in the deserts of Central Asia and on the Tibetan Plateau were dated to 40-30 kyr and to late glacial/Early to Mid-Holocene periods when wetter climatic conditions persisted in all probability all over Tibet and Central Asia. The humid conditions also influenced the prehistoric human development on the Tibetan Plateau and adjacent areas. The first evidence of early man on the Tibetan Plateau can be found around 30 kyr. A second phase of human occupation during the Neolithic period is assumed to belong to the early and middle Holocene. This Holocene climatic change can also be deduced from the advances of glaciers, soil development, and pollen analysis. There is a climatic change in the Late Holocene towards cooler and in some areas wetter climatic conditions. At present, the Qangtang Plateau (northwestern Tibet) is uninhabited due to modern climatic conditions, which are unfavourable to grassland. This region was used by Mesolithic and Neolithic hunters during the Holocene climatic optimum. Based on present-day July temperature and annual precipitation, a calculation of the Mid-Holocene climatic conditions provides evidence for an enlargement of areas favourable for grazing.

## Introduction

The Tibetan Plateau, known as the Qinghai-Xizang Plateau in Chinese literature, covers an area of approximately 2 million km$^2$ and is the highest plateau of any significant extent on the Earth's surface It is located between the Karakoram and Himalayan ranges in the south and Altyn Tagh and Kunlun ranges in the north. The mean elevation ranges between 4,500 and 5,000 m, and many isolated mountain massifs are above 6,000 to 7,000 m amsl.

In general, the Tibetan Plateau plays a major role in the Asian monsoon system. This in turn even affects global climate and global climatic change (Böhner 1994, 1996; Flohn 1981, 1987; Murakami 1987). It is accepted that the Cenozoic uplift of the Tibetan Plateau increased the aridity of Central Asia which induced the monsoon system and the development of loess sequences on the Chinese Loess-Plateau (e.g. Prell and Kutzbach 1992; Ruddiman and Kutzbach 1989). Meyerhoff *et al.* (1991) compiled all available data and concluded that the uplift of the Tibetan Plateau started in the Early Miocene and accelerated during the Pleistocene.

From a climatological and meteorological point of view the extent of past lakes and glaciers are important, as they show, that the precipitation was sufficient to allow glaciers or lakes to expand. The extent of the glaciation on the Tibetan Plateau must also have influenced the distribution of the upper air circulation patterns, and therefore the tracks of mesoscale cyclones, and regional precipitation. In addition, the large lakes of the Tibetan Plateau, the Qaidam basin, and the Gobi Desert, must have affected the local humidity and autochthonous precipitation. Therefore, the abundance and variation of late Quaternary ice and lakes on the Tibetan Plateau are of particular interest for the reconstruction of the palaeoenvironment and climatic change.

Investigations of Quaternary environmental changes and palaeoclimate evolution on the Tibetan Plateau have focussed mainly on the distribution and timing of lake level changes and Pleistocene glaciations of special areas. In addition, the loess and loess-like sediments especially from the adjacent regions as the Chinese Loess Plateau provide evidence for palaeoclimatic change (e.g. An *et al.* 1991; Hovan *et al.* 1989; Liu *et al.* 1985). This paper summarises the climatic change of the Late Quaternary with respect to fluctuations of glaciers, lake level changes and ancient shoreline evidence of Tibet, and some sparse information from the literature on human occupation of the Plateau. In addition, we have attempted to determine the climatic conditions neccessary for present-day agriculture and animal husbandry in order to estimate the area on the Tibetan Plateau which could be used by the Neolithic hunter-gatherer communities when the summer temperatures were approximately 2°C warmer than present day conditions.

The palaeoclimatic results derived from inland fluctuations of glaciers, lake level changes, dust (loess) records, palaeovegetation and traces of early man in the Tibetan Plateau were compiled by means of literature and by our own field investigations between 1988 to 1998. A review with respect to literature and our own results is given in Lehmkuhl and Haselein (1999).

Due to the different climatic conditions, vegetation cover and land use, the Tibetan Plateau can be divided roughly into 5 different regions (see Fig. 1):

Northeastern Tibet or Qinghai: This region includes the upper reaches of the Yangtze and Yellow rivers. The annual rainfall is above 200 mm/year and allows nomadism in most areas. There is agriculture in these basins and valleys below 3,100 m amsl in the northern part (Xining, Aba) and 3,700 m amsl in the southern part (Garze, Yushu). The northern part of this area belongs to the dry internal Qaidam Basin with a mean elevation between 2,900 and 3,200 m amsl, and the Qilian Shan mountain system, respectively

The south-eastern part, which is characterised by deep valleys and gorges of several large north-south flowing streams. Due to the relatively high precipitation and deep incised valleys this is the sector of Tibet with the largest quantity of forest which stretches up to elevations of more than 4,800 m amsl, and with agriculture in the valleys.

A southern part of the Plateau, north of the Himalaya, in the catchment areas of the Yarlung Tsangpo and upper Indus rivers. Due to the relatively low elevation and sufficient precipitation or irrigation water there is quite a lot of agriculture in this area. Barley is cultivated up to more than 4,700 m amsl.

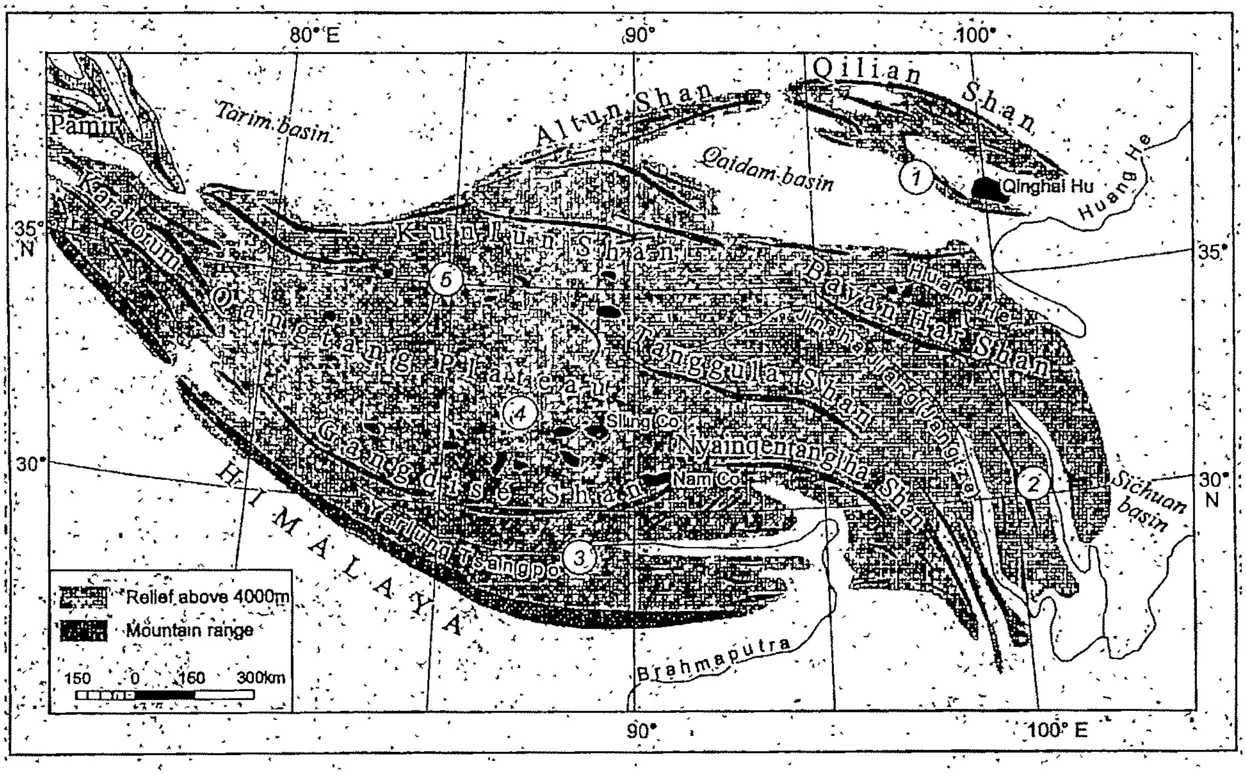

**Fig. 1**: Map of the study area. The numbers indicate the 5 main regions of the Tibetan Plateau described in the text

The western and central part of the Tibetan Plateau above 4,500 m amsl, north of the Gangdise Shan with numerous lakes in interior basins. The precipitation above 100 mm is sufficient to allow nomadism up to elevations of more than 5,500 m amsl.

The northwestern and northern part of the Tibetan Plateau, north of the Tanggula Shan and south of the Kunlun Shan including the Qangtang Plateau. This dry area is characterised by widespread continuous permafrost at elevations above 4,800 m amsl, and the annual precipitation ranges between 150 and < 50 mm.

## Climatic Change Derived from Mountain Glaciations and other Geomorphic Features

Since the beginning of this century there has been a debate on the extent of glaciers or even of a Tibetan ice sheet during the Pleistocene glaciations. In addition, the timing and spatial distribution of Quaternary glaciations of the Tibetan Plateau and adjacent areas is of special interest. Trinkler (1930) had already postulated a large ice sheet on the Plateau south of the western Kunlun Mountains. Kuhle (e.g. 1988, 1998) has proposed a theory implying the existence of a widespread ice cover of 2.4 million km$^2$ over nearly the whole of the Tibetan Plateau during the different Pleistocene glaciations. However, most researchers agree that glaciations on the Tibetan Plateau were characterised by valley glaciers or small mountain glaciations but not an extensive ice sheet (e.g. Derbyshire *et al.* 1991; Hövermann *et al.* 1993; Hövermann and Lehmkuhl 1994; Li *et al.* 1991; Lehmkuhl 1995,1998; Lehmkuhl *et al.* 1998; Pu 1991; Shi *et al.* 1992; Zheng 1989; Zheng and Rutter 1998; Zhou and Li 1998). Li *et al.* (1991) published a map with the extent of Pleistocene glaciations on the Tibetan Plateau based on Chinese research. The different opinions are summarised by Lehmkuhl *et al.* (1998).

One reason for the differing opinions on the extent and distribution of Pleistocene glaciations on and around the Tibetan Plateau is the present lack of a uniform division and terminology for the different end moraine sequences or till deposits in the various mountain areas (Lehmkuhl 1997a, 1998). Some relative chronologies exist for mountain glacier fluctuations, but the timing is poorly understood due to the lack of absolute dating of moraines. Even a uniform relative stratigraphy based on depression of snowlines as, for example, in the European Alps is not available (Lehmkuhl 1995; Lehmkuhl and Haselein 1999). Most of the dating related to the timing of glaciations in the Himalayas and in Tibet is summarised in Benn and Owen (1998).

According to Chinese scientists the Last Glacial Maximum (LGM) ended c. 15 kyr (e.g. Li and Shi 1992) or c. 13 kyr (Li and Pan 1989). In the Chinese literature the last glaciation is often divided into two stages (approximately equivalent to marine oxygen isotope stages Stage 2 and 4). These were interrupted by an Interstadial that lasted from about 55 to 32 kyr (e.g. Li and Pan 1989; Liu *et al.* 1985; Zhang *et al.* 1991). Maximum advances of glaciers are dated for both stages in various mountain areas (see Benn and Owen 1998; Lehmkuhl 1995; Owen *et al.* 1997 for further details).

Only a few results have been published on Holocene and Late-glacial fluctuations of mountain glaciers on the Tibetan Plateau and surrounding areas (Lehmkuhl 1997a). Different Chinese authors argue for several advances of glaciers in the Holocene, but no further late-glacial end-moraines or ice marginal limits up to the LGM terminal moraines are separated. In addition, a lot of radiocarbon dating has been undertaken on organic material that overlies terminal moraines on the Tibetan Plateau. These dates give minimum ages and consequently, only a few Pleistocene and Holocene glacier advances are dated with any degree of confidence.

The Early Holocene glaciers were approximately the same size as they are today. This is confirmed by the peat bogs in the vicinity of modern glaciers. For example, at the Kakitu mountains (Qilian Shan, neighbouring to the Dunde ice cap) a peat bog close to the modern glaciers began to develop at about 9400 B.P. (Beug 1987) and other peat bogs on the Tibetan Plateau started developing about 10 kyr (e.g. Lehmkuhl 1995; Wang and Fan 1987). Evidence for the Neoglacial (4000 to 3000 B.P.) and Little Ice Age events in the Late Holocene (e.g. Wu and Lin 1988), is provided by moraines in southern Tibet dated by wood and branches in them (Arza glacier, see Wang and Fan 1987) and other investigations (see Pu 1991). This late Holocene temperature depression of about 1 to 2°C at around 3 to 1.5 kyr and for the Little Ice Age can also be derived from buried soils in the alpine meadows in eastern Tibet (Lehmkuhl 1995).

In addition, the sediment cover and aeolian mantles on bed rock or terraces provide further palaeoclimatic evidence. Periglacial features, e.g. ice wedges, cryoturbations, and solifluction layers provide evidence for LGM palaeotemperatures (Lehmkuhl 1995; Lehmkuhl *et al.* 1998). Buried soils under solifluction lobes in Eastern Tibet provide evidence for cooler conditions since 3 kyr (Lehmkuhl 1995).

## Lake Level Changes and the Timing of Late Quaternary Climatic Change

The different palaeoclimatic evidence on the Tibetan Plateau and adjacent areas are summarised in Figure 2. Glacier advances are observed for this area during the Oxygen Isotope Stage 4 and 2 (e.g. Benn and Owen 1998) and for the Late-glacial around 15 kyr.

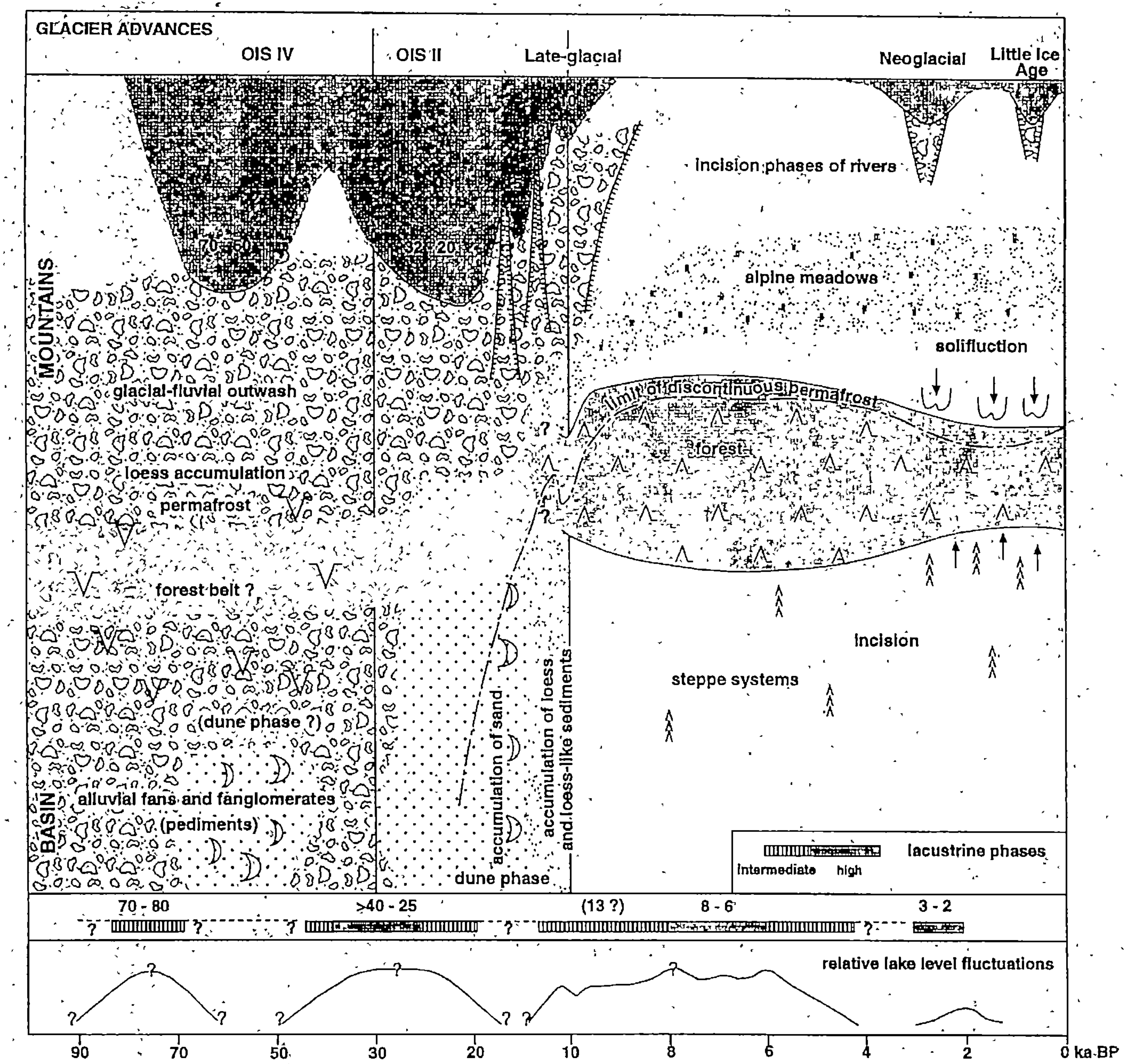

**Fig. 2**: Landscape development including lake level changes, glacier fluctuations in the mountains (top) and basins (bottom) of Central Asia during the last 100,000 years. The lacustrine phases are generalised from different sources (modified from Lehmkuhl and Haselein 1999)

Today lakes cover an area of approximately 30,000 km$^2$ on the Tibetan Plateau between 74°-98°E and 28°-40°N (Lehmkuhl and Haselein 1999). Most lakes have interior drainage. During the Late Quaternary and Holocene the size of these lakes continuously decreased, so that at presently they are reduced to a third, and even up to a tenth of their former maximum sizes. Summaries on Late Quaternary lake level fluctuations are given e.g. by Fang (1991) and Qin and Yu (1998). The maximum extent of Late Quaternary lake levels is presented in two Chinese maps (Atlas of Tibetan Plateau 1990; Li *et al.* 1991). Most other papers focus more on a regional scale. A review and discussion of lake level history in Central Asia with respect to primary literature and our own results is discussed in detail in Lehmkuhl and Haselein (1999). Based on field investigations, literature and satellite images (Atlas of False Colour Landsat Images of China 1983) they calculated the area of present-day playas, which are assumed to show evidence for higher lake levels in the past or even the existence of a palaeolake, of about 20,500 km². This means an extension in the lake area of more than 60% as compared to the present size, which is a minimum value for the lake level variations. The evidence of higher lakeshores based on this source together with palaeolake levels reported in the Atlas of Tibetan Plateau (1990) suggest that the overall area of palaeolakes was approximately 84,000 km². This is interpreted as a maximum value for Late Quaternary lake level fluctuations. The question arises, whether high lake levels on the Tibetan Plateau occurred in general simultaneously or not. In the Chinese literature different opinions about the chronology of even regional scale lake level changes have been published (e.g. Wang *et al.* 1990; Li and Shi 1992). Consequently Fang (1991: 47) summarises: "On the Qinghai-Tibetan Plateau and alpine regions of Western and Southwestern China ... lake levels reached their maximum as early as about 15,000 and/or 12,000 B.P. after the LGM desiccation or deflation. ... Western China, like other areas of the country, experienced prolonged and intense aridity between 16,000 and 10,000 yr B.P. . ." A review of lake level history since 30 kyr in Central Asia with respect to primary literature and our own results shows that there is obviously no *clearly defined* humid or arid interval and no period of high or low lake level respectively, which occurred on the *whole* Plateau at the same time, although higher lake levels in the deserts of Central Asia and on the Tibetan Plateau were dated to > 40 to 25 kyr (equivalent to the Oxygen Isotope Stage 3). However, they show a widespread range in this time frame. One reasonable explanation for this may be the usage of different dating methods (Lehmkuhl and Haselein 1999).

### *Regional Pattern of High Lake Level/Humid Phases*

#### Western Tibet

The interpretation of the lake level data from Western Tibet (Wang *et al.* 1990; Li *et al.* 1989; Fang 1991; Li and Shi 1992) suggests higher lake levels between > 40-24 kyr and ~16-13 kyr The uncorrected ages from Bangong Co (Fontes *et al.* 1993) show that between ~16 to ~12.7 kyr more humid climatic conditions with positive precipitation-evaporation ratio were established. After ~12.7 kyr the lake level decreased. This is consistent with observations from Sumxi Co (Gasse *et al.* 1991; Van Campo and Gasse 1993) and the results of Wang *et al.* (1990) from other Western Tibetan lakes suggesting an arid climate after 18.5 kyr and a high lake level period between 16 and 13 kyr Early- to Middle-Holocene wet and warm climatic conditions were established around 8 kyr and lasted until 5.5 kyr at Sumxi- and Longmu Co (Gasse *et al.* 1991; Van Campo and Gasse 1993). The highest levels of these lakes occurred around 7.7 to 7 kyr, when both basins formed a single lake (Gasse *et al.* 1991). Higher lake levels are reported for other Western Tibet basins between 9 and 5 kyr (Li and Shi 1992).

#### Central Tibet

Relatively little information concerning lake evolution in Central Tibet is available at present. In this part of the Plateau there are a few dates on higher lake levels, but there is still a lack of serious investigation in this vast area. Higher lake levels in the region of the central Plateau may have occurred during the Late Pleistocene at 39-23 kyr and 11-9 kyr while the lowest lake level was from 22-16 kyr (Wang 1990). Frenzel (1994) dated a higher shoreline at Peng Co to 48-45 kyr and a higher terrace of theYamzu Yum Co to 22 and 20 kyr. At the southern margin of the lake Nam Co (Tengri Nur) Lehmkuhl and Haselein (1999) provide evidence for two major glaciations interrupted by a high lake period and a decline of the lake following the youngest glaciation. Weathering characteristics and the overlying strata indicate that the youngest glacial stage is equivalent to the last glacial cycle (corresponding to the Oxygen Isotope Stage 2). Traces of higher lake levels below this ice margin and on top of the glaciofluvial outwash are equivalent in age to the late-glacial/ early to Mid-Holocene, when wetter climatic conditions persisted. The older moraine probably corresponds to the early stage of the last glaciation (equivalent to Oxygen Isotope Stage 4) or to the penultimate glaciation (Oxygen Isotope Stage 6). The highest, 30 m high, shoreline may date to the last Interstadial age (equivalent to Oxygen Isotope Stage 3). This supports the view that cold phases during the last glacial correspond with the maximum extent of glaciers and periglacial activity that produced large alluvial fans alternating with periods of high lake stands in many areas of Central Asia (Lehmkuhl and Haselein 1999).

#### Northeastern Tibet

At Qaidam basin the interval between 32 and 24 kyr (the "Anaglacial" according to Hövermann and Süssenberger 1986) and probably some time before 32 kyr is characterised by advancing glaciers and the rising lake level of Palaeo-Qaidam-Lake. Between 24 and 21 kyr initial lake shrinking due to reduced rainfall occured. Chen and Bowler (1986) found sedimentary evidence for freshwater to slightly saline lakes under more humid conditions in the Qarhan area between 40 and 25 kyr. From the same area Liu (1991) reports evidence for freshwater lakes and very humid climate from 38.9 to 28.7 kyr and since 25 kyr a tendency towards desiccation. Dates between 31.8 and 23.8 kyr derived from higher lakeshores (+8 to +13m) of the Xiao Qaidam (Huang 1994) indicate a higher lake level too. In addition, vegetation evidence (Kong 1993) suggests humid environmental conditions between 31 and 24 kyr. The highest lakeshore of Qinghai Hu is tentatively dated to ~38 kyr and a minor highstand occurred between 33.8 and 23.6 kyr (Liu 1991). After a period of lake shrinking the lake level rises again from 12 kyr until 6 kyr (Lister *et al.* 1991; Kelts *et al.* 1989). Huang

(1994) reports an age of 11 kyr for a +100 m higher lake level. A 10 to 12 m higher shoreline at Xin Xin Hu and lacustrine sediments at Sogqen and Maligango have been dated by Frenzel (1994) to 22 kyr.

Inner Mongolia

In the Gashun/Sogun Nur area the highest lake levels of between +28 to +32m occurred between 41 and ~33 kyr. At Baijian Hu, the maximum extension of the lake area was between 40 and 23 kyr. In both basins there is a trend towards lake shrinking although higher lake levels exist until 23 kyr. Around 21 kyr the lake level of Gaxun Nur was 15 m and around 19 kyr 18 m lowered. A hyperarid interval ended at Baijian Hu around 13 kyr as the lake level rose again up to the +23m level. A freshwater lake was established at Gashun/Sogun Nur after 11.3 kyr. At Bajain Hu, a minor high lake level phase occurred between 8.7 and 7.3 kyr and at Gaxun Nur/Sogu Nur between 6.5 and 4.5 kyr (Wünnemann *et al.* 1998; Wünnemann and Pachur 1998). Humid climatic conditions appeared at lake Manas between 37 and 32 kyr (Rhodes *et al.* 1996). Another humid phase after long term aridity is placed by Rhodes *et al.* (1996) in the Late-glacial period (around 12 kyr). In addition, pollen and sedimentological evidence from western Loess Plateau indicates a smaller extent of the Gobi during cold and moist periods viz. 73 to 60 and 27 to 19 kyr (Feng *et al.* 1998).

### *Evidence for Hyperarid Phases*

Hyperarid climatic conditions occured in Central Asia, with the exception of Western Tibet, in the Late-glacial period, the so-called Kataglacial (c. 24 to 15/13 kyr). Cold and dry climatic conditions occured in the Qaidam Basin since 24 kyr and extremely arid conditions between 15 and 9 kyr. At Bangong Co arid conditions prevailed before ~16.2 kyr (Fontes *et al.* 1993). There is evidence that Lop Lake experienced a period of desiccation after 20.8 kyr (Fang 1991). At Qinghai lake as well as in the Qaidam Basin arid conditions are assumed from 17 to 12 kyr. The lakes in the Gobi desert (Gashun/Sogun Nur) dried out from 19 to 13 kyr. During this time 3 m of dune sand accumulated. At the Helan Shan the climate was more arid than today between 23 and soon after 10 kyr (Hofmann 1993). The Gobi desert expanded from 60 to 50 kyr and 19 to 10 kyr (Feng *et al.* 1998) indicating that a greater area was affected by hyperarid climatic conditions during this period. TL-data from dune sand in the Mu Us Desert located north of the Loess Plateau prepared by Sun *et al.* (1998) indicate a hyperarid environment between 75±9 and 55±4 kyr and shortly before17±1 until soon after 10±1 kyr. Hyperarid climatic conditions before 13 kyr are indicated by deposition of aeolian sand (Zhou *et al.* 1996) in the desert-loess transition zone of central Loess Plateau. According to Fang (1991) extensive dune sands accumulated at the northern Qinghai-Tibetan Plateau region (Gonghe Basin) from 14.8 to 12.7 kyr. Synoptic interpretation of palaeoenvironmental information from southeastern Tibet given by Yan and Petit-Maire (1994) show that an arid episode probably occurred after the LGM lasting until around 14 kyr. Frenzel (1994) suggests that moisture availability on the whole Tibetan Plateau was generally lower than today between approximately 20 and 10 kyr.

However, as mentioned above there is in the western part of the Tibetan Plateau local evidence for a return to wetter conditions at approximately 16 to 15 kyr. This change towards more humid and warmer conditions began in the eastern part of the Plateau around 13 to 10 kyr with a gradual reinforcement of the summer monsoon influence in central China (e.g. Pachur *et al.* 1995). Rapid, short-termed climatic oscillations, such as the Younger Dryas event might be recorded in the loess profiles (An *et al.* 1993 and Zhou *et al.* 1996) or in lacustrine sediments in western Tibet (e.g. Gasse *et al.* 1991).

## Holocene Climatic Change

According to most authors (e.g. Wang and Fan 1987; Wu and Lin 1988), three Holocene climatic phases could be distinguished for the research area:

1. A humid and warm Early Holocene (10,000 to 7,500 B.P.), often manifested by the first formation of peat bogs and higher lake levels within the Qaidam Basin as well as in western and southern Tibet.
2. The Middle Holocene (7,500/6,000 to 3,000 B.P.) with a warmer and more humid climate in comparison with present conditions, derived from higher lake levels in Tibet and palynological studies as well. This was the warmest period on the Tibetan Plateau. According to some Chinese authors (e.g. Wang and Fan 1987; Wu and Lin 1988) the annual average air temperatures during the Holocene climatic optimum were estimated to be 2 to 4°C or even 3 to 5°C, respectively, higher than today.
3. The cooler (and therefore partly more humid) Late Holocene (beginning 3,000 B.P.), is shown by glacier advances in southern Tibet, historical sources of the Chinese main areas, as well as palynological results (e.g. Pu 1991; Wang and Fan 1987; Sun and Chen 1991; Lehmkuhl 1995; Schlütz 1995, 1999). In Eastern Tibet this period begins at 4,000/3,000 B.P. as indicated by older humic layers overridden by solifluction lobes. According to the results from the Nianbaoyeze area (eastern Tibet) it is sometimes impossible to divide climatic and anthropogenic influences on the palaeoecological environment within the late Holocene (Lehmkuhl 1995; Schlütz 1995). In addition, for the Taklimagan desert, north of the Tibetan Plateau, at about 2000 B.P. and during the

Little Ice Age interval wet phases were reported (see Yang 1991).

**Archaeological Evidence**

Only a little has been published on the archaeology of the vast region. A compilation of the Chinese research is given by Huang (1994). According to the Chinese investigations, two main phases of human activity could be found up to now in this large area. The first one, Palaeolithic in age, was dated to be around 30 kyr (31.8 to 23.8 kyr: Huang 1994: 204) at Xiao Qaidam. This site is associated with a high lake level of the palaeolake Qaidam. The second, main period starts at the end of the Pleistocene. These sites date between 7.5 to 3 kyr (Huang 1994: 213). Most sites are also situated close to the former high beach lines. For example, a late-glacial/Early Holocene site at Geting is situated 133 m above the present lake level of the Siling Co (Huang 1994: 205). In addition, Cui *et al.* (1995) reported on Neolithic sites in the Kunlun Mountain Pass area south of Golmud. One famous Neolithic site is Karou 12 km south of Qamdo city with a settlement of 10,000 m$^2$ at 3,100 m amsl. The 7,968 stone artefacts consists of heavy-duty tools, light-duty tools and microliths. The fauna belongs to a much warmer and more humid climate than today. The early stage of this site is dated by radiocarbon to 4,900±100 B.P. and 4,280±100 B.P., the later stage to 3,930±80 B.P. (Huang 1994: 207).

Li *et al.* (1985) and Wang and Fang (1987) reported on Neolithic sites found at several places on the Tibetan Plateau. Human activity on the Tibetan Plateau moved southward during the Holocene. At present, the northern part of the Plateau, the Qangtang Plateau (Fig. 1 region 5), is almost uninhabited. However, in this region, many archaeological sites from the Palaeolithic and Mesolithic periods (5000-4000 B.C.) have been discovered. Neolithic hunting sites including tools can be found up to elevations of 5,200 m amsl. Huang (1994) concludes that the groups of prehistoric humans who occupied northern Qinghai and Tibet came from the Loess Plateau of China, whereas other groups might have arrived at the river valleys of southern Tibet coming from south of the Himalayas. In Figures 3 and 4 we summarised the sites from the literature and tried to find the recent conditions suitable for agriculture and nomadism. It is likely that the succeeding unfavourable

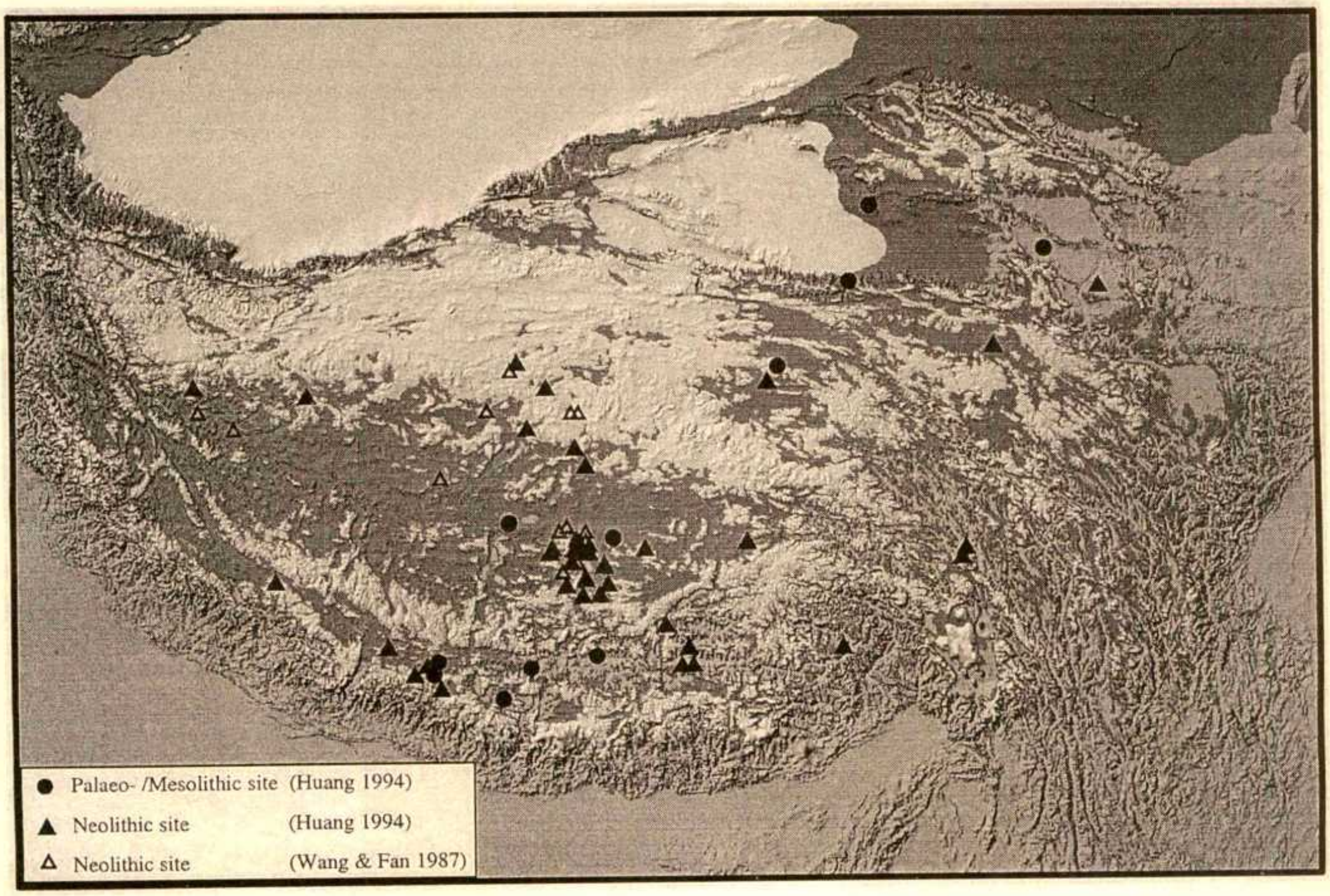
● Palaeo- /Mesolithic site (Huang 1994)
▲ Neolithic site (Huang 1994)
△ Neolithic site (Wang & Fan 1987)

**Fig. 3**: Recent climatic conditions in areas favourable for agriculture: elevation below 4500 m amsl, July temperatures >10° C, annual precipitation >200 mm (light grey). For nomadism: 5500 m amsl, >7° C July temperature and below 50mm annual precipitation (dark grey). The white shaded area indicates deserts and high mountain regions

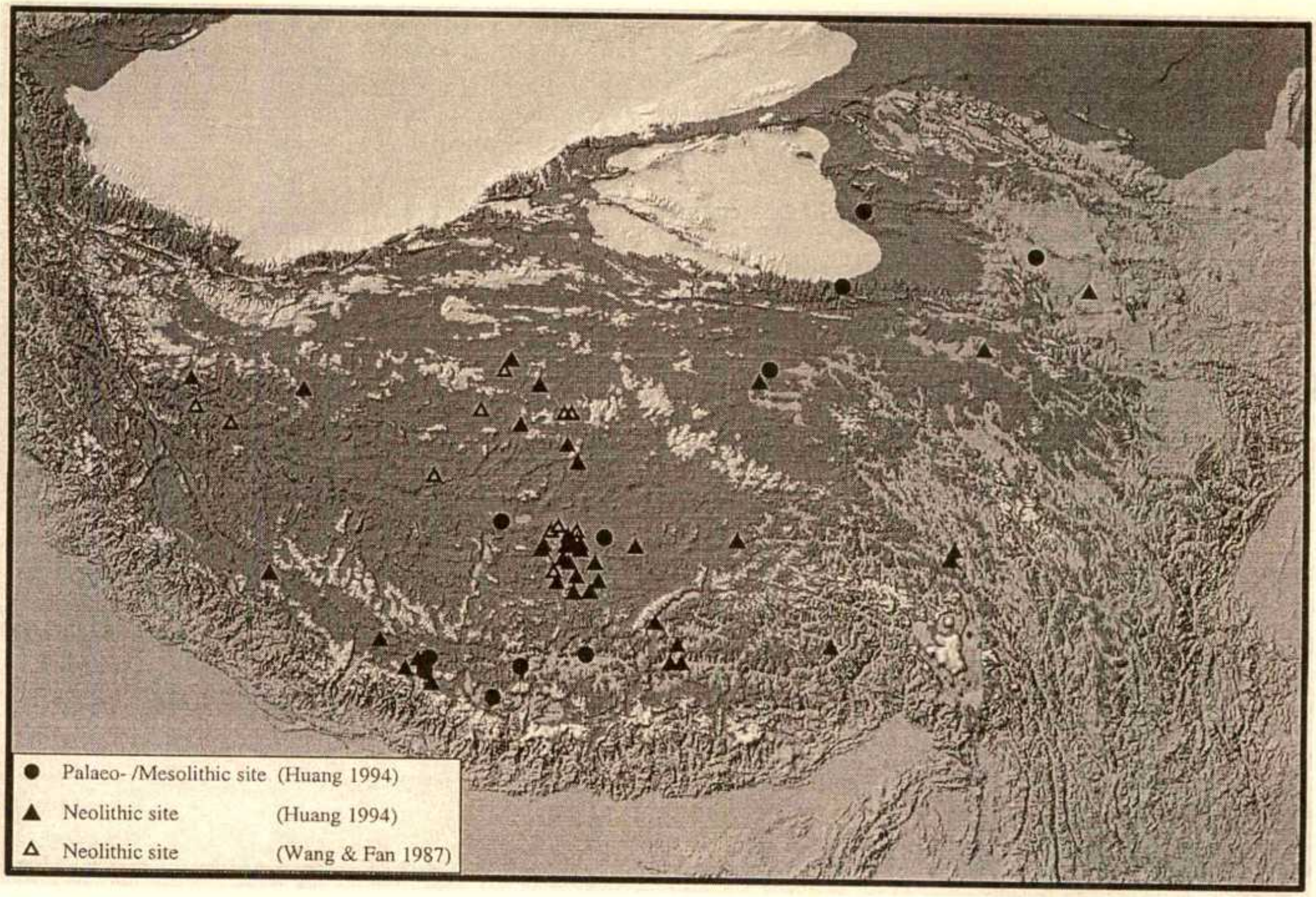
● Palaeo- /Mesolithic site (Huang 1994)
▲ Neolithic site (Huang 1994)
△ Neolithic site (Wang & Fan 1987)

**Fig. 4**: Calculated climatic conditions for the Mid Holocene climatic optimum based on the present day values. Areas favourable for agriculture: elevation below 4500m amsl, July temperatures > 8° C, annual precipitation > 200 mm (light grey). For nomadism: 5500 m amsl, > 5° C July temperature and below 50mm annual precipitation (dark grey). The white shaded area indicates deserts and high mountain regions

climate in the Late Holocene forced the people to migrate southward during the late Mesolithic era (after Liu and Wang 1981; cited by Wang and Fan 1987: 59).

However, natural environmental changes and the evolution of human society may have affected each other. The transition from hunter-gatherer communities to sedentary agriculturalism and nomadism being accompanied by increasing technological sophistication. Therefore the areas at the margins of the inhabited world might be of no further interest for nomads and farmers, but, even for the early hunters the vegetation must have been be sufficient to allow large herds of grazing animals. S. Hedin crossed the southern area of Qangtang Plateau (1907/1908) and there was not enough grass for his yaks and horses in this area, and for more than 70 days he did not find any traces of nomads (Hedin 1985).

### Modelling of Environment Suitable for Agriculture or Husbandry

The modelling of environment, regarding the spatial distribution of temperature (July) and precipitation amount, represented by grid-data in a resolution of 2000 x 2000 m per pixel (Bi-Parallel Alberts Equal Area Projection) was attempted. The regionalisation of longstanding means, recorded at the climate stations of the investigation area and adjacent areas is based on statistic and deterministic approaches of climatic modelling (Böhner 1996; Böhner and Schröder 1999). The regionalisation identifies and quantifies the influences of circulation patterns (represented by the geopotential altitude and temperature of the 500-hPa and 850-hPa level and the sea-level pressure) as well as the specific relief-situation at each climate station, represented by complex-analytic relief parameters (derived from a digital elevation model in a resolution of 1000 x 1000 m) on the spatial distribution of temperature and precipitation amount. As far as available, the regionalised data mainly refer to the 30-year standard period 1951-1980. According to different maps (e.g. vegetation, soil, land use) and field observations of the first author, we calculated the modern climatic conditions. Areas favourable for agriculture lie below 4,500 m amsl and the model shows July temperatures above 10°C with an annual precipitation above 200 mm (this includes some areas with irrigated agriculture). For nomadism, which is possible up to 5,500 m amsl the July temperature should be above 7° C and the minimum annual precipitation should be 50 mm. Fig. 3 shows the areas favourable for agriculture and nomadism today.

As mentioned above, the temperature during the Holocene climatic optimum was about 3-5° C higher than today. In Figure 4 the areas favourable for agriculture and nomadism with a positive temperature deviation of 2° C and the modern precipitation values is shown. Even with this minimum positive temperature deviation the area suitable for nomadism covers almost the entire Qangtang Plateau.

## Conclusion

The conclusion of our own research work is in accordance with the literature, demonstrating that cold phases of the last glaciation correlate with the maximum extent of glaciers and periglacial activity including large alluvial fans. These features alternate with periods of high lake levels in most areas of Central Asia. It is likely that periods of high lake levels coincide with the first appearance of prehistoric man on the Tibetan Plateau and adjacent areas. Present day climatic conditions in the northern part of the Tibetan Plateau make it unsuitable for grazing mammals and it is consequently uninhabited. According to archaeological evidence this area was used by early hunters during the warmer and wetter Holocene climatic optimum. Calculations based on present day climatic conditions on the Plateau show, that a temperature increase of 2° C enlarge the grazing area towards the north.

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# Late Quaternary Alluvial History and Archaeological Sites in the Nimar Region of Western Madhya Pradesh, India

Sheila Mishra, S.B. Ota,[1] Gurudas Shete, Sonali Naik, and B.C. Deotare

Department of Archaeology
Deccan College
Pune 411 006

1 Archaeological Survey of India
Calcutta Circle
Calcutta 700 004

## Abstract

A number of archaeological sites along the Narmada River in the Nimar region have been studied including Navdatoli, Nawarakheri, Pipri, Utawad, Chilkalda, Khaparkhera and Karondhia. It has been possible to identify a number of geomorphological "events" and to date them in relation to the archaeological sites. These include a phase of Late Pleistocene aggradation, incision and soil formation in the pre-Chalcolithic period, and a post-Chalcolithic phase of aggradation and incision. These changes in the fluvial activity of the Narmada are due to changes in climate. The human settlements also appear to be sensitive to changes in climate.

## Introduction

The Narmada is one of the major rivers of peninsular India. It flows from east to west for a distance of 1300 km. It divides the Subcontinent into north and south and follows a line of ancient crustal weakness. The Narmada course alternates between bedrock and alluvial stretches, subdividing it into a number of sub-basins. From its source at Amarkantak up to Jabalpur it has a rocky valley. Downstream of Jabalpur it flows through a gorge at Bhedaghat after which a major alluvial basin begins. This central Narmada Basin has been the focus of most Quaternary geological, palaeontological and archaeological studies. Between Harda and Onkareshwar the Narmada enters a second bedrock stretch. The region between Barwah and Barwani, after Onkareshwar is a second alluvial stretch. After Barwani the Narmada enters a bedrock stretch again before finally reaching the Gujarat alluvial plain and joining the Arabian Sea at Bharuch. In this paper the major data were obtained from archaeological studies of various Chalcolithic sites in the Barwah-Barwani stretch of the Narmada (Fig. 1). This alluvial plain is known as "Nimar".

The Nimar region occupies the Narmada Basin between the two major nick points of Onkareshwar near Barwah and Hiranphal near Barwani. In this 120 km stretch, the Narmada flows in a narrow alluvial plain bounded on the north by the Vindhyan escarpment and on the south by the Satpuras. This entire region is covered with Deccan Trap basalts except for the Nimar Sandstone which is of Cretaceous age, underlies the Deccan Trap and is exposed at the base of the Vindhyan escarpment in the north of the valley. The climate is semi-arid, with the western part in the rain shadow of the Satpuras and increasing rainfall as one travels east. The northerly tributaries have small catchments and originate close to the crest line of the Vindhyan escarpment, while the southerly tributaries drain the areas of the northern side of the Satpuras. All the tributaries of the Narmada have very small drainage areas compared to the Narmada, mainly because of the elongated shape of its basin.

Some archaeological work was carried out in this region prior to Independence by the Holkar State at Kasrawad, near Maheshwar where a stupa was identified (Diskalkar 1946). The Nimar region was one of the earliest areas for Chalcolithic studies. Soon after the discovery of the Jorwe pottery at Jorwe in Maharashtra, excavations and explorations were carried out by Sankalia (1952-53, 1957-59) at Maheshwar and Navdatoli (Sankalia *et al.* 1958, 1971). This work was absolutely crucial to the development of protohistoric studies in India. Later however little further work was done until the Prehistory Branch of the Archaeological Survey of India (ASI), Nagpur, took up salvage work in the reservoir area of the Sardar Sarovar dam.

The ASI excavated a number of Chalcolithic sites–Pipri, Utawad, Khaparkhera and Nawarakhedi (*IAR*, in press) and this material is currently under study by them with publication expected in due course. Mishra, along with Naik, Shete and Deotare collaborated with the ASI Prehistory Branch on the geomorphological aspects of the sites which are partly reported here.

Prehistoric studies had been carried out by Armand (1983) who excavated a chopper-chopping tool site at Durkhadi Nala, near Maheshwar. Mishra (1985) explored

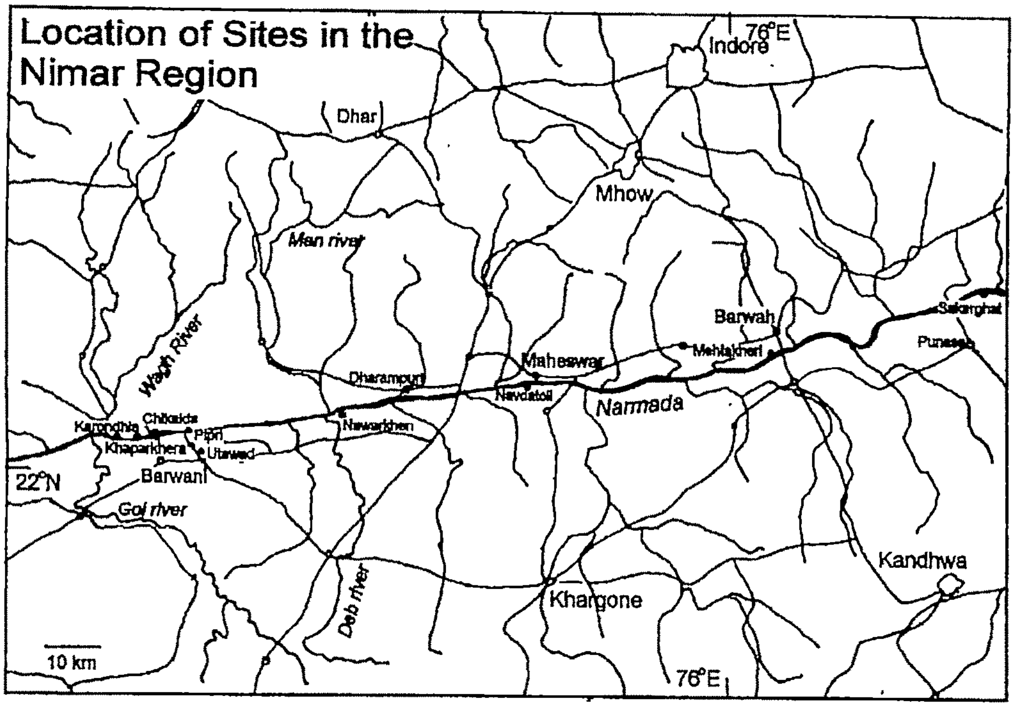

**Fig. 1**: Location of sites in the Nimar region of the Narmada Valley

the region for her Ph.D. work and later, excavated the Upper Palaeolithic site of Mehtakheri, partly under the sponsorship of the Indira Gandhi Rashtriya Manav Sangrahalaya, Bhopal.

Based on a synthesis of all this work, it can be seen that Late Quaternary climatic change has left its imprint on the Narmada deposits. The presence of archaeological material helps in the construction of a chronology and in understanding the human response to this climatic change. A number of geomorphic changes can be identified from this data. The first is a basin-wide aggradation during the Late Pleistocene. The second is an incisional phase of the Early Holocene, during which period soil developed on the Late Pleistocene alluvium. During post-Chalcolithic times a second phase of filling followed by incision can be identified. During the Early Historical period, settlements were affected by floods. A continuous sequence of habitation, from the Chalcolithic to Early Historic periods, is seen both at Navdatoli and Khaparkhera. However, it appears that in the period between the Early Historic and Medieval periods there is a reduction in the settlements in the region. This record is in agreement with that obtained (Kale *et al.* 1996) from the Slack Water Deposits (SWD) at Sakarghat, near Punasa.

## Discussion of the Chalcolithic Sites

### *Navdatoli*

The site of Navdatoli was excavated by Sankalia (Sankalia *et al.* 1958, 1971). The mound is on the left bank of the Narmada, opposite the town of Maheshwar. The Chalcolithic mound overlies Pleistocene silt with a soil developed on it. Presently the mound is about half a kilometre away from the river. This intervening zone is filled in with Holocene silt and post-dates the occupation of the mound. A stupa on the mound was destroyed by a flood after which the settlement was abandoned. The effects of this flood are seen not only in its destruction of the stupa but also as a scour line and erosion on the mound (Sankalia *et al.* 1958). The Narmada River therefore has shifted north since the post-Early Historic period.

Sankalia *et al.* (1958) date the Early Historical cultural sequence by the presence of NBP (Northern Black Polished) ware and RPW (Red Polished Ware). They do not identify any gap between the Early Historic period and the Chalcolithic. A gap is identified instead between the Early Historic and Medieval deposits. The continuous cultural sequence between the Early Historic and Chalcolithic at Navdatoli is in contrast to many other sites in western India. The radiocarbon dates for Navdatoli, which became available later (Sankalia *et al.* 1971) show a range of 200 years between 3,500 to 3,000 b.p. for the Chalcolithic occupation (Table 1).

**Table 1**: Radiocarbon dates from the Narmada Valley

| Lab no | Date | Context | Reference |
|---|---|---|---|
| TF 59 | 3,380±105 | Tr 1A, layer 8 Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 200 | 3,475±127 | Tr II layer 8, Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 201 | 3,492±128 | FII 8, Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 202 | 3,508±128 | Tr 1A, layer 6, Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 204 | 3,449±127 | Tr I, layer 4, Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 205 | 3,294±160 | Tr I, layer 2, Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 475 | 3,455±70 | Navdatoli | Sankalia, Deo and Ansari 1971 |
| P 478 | 4,225±69 | Tr I, Navdatoli | Sankalia, Deo and Ansari 1971 |
| BS 1425 | 1,910±100 | Nawarakhedi | Unpublished |
| A 9446 | 15,680 +440/-415 | Khaparkhera | Unpublished |
| BS 286 | 25,160±850 | Dharampuri | Mishra 1985 |
| A 6518 | 30,680+1040/-920 | Mehtakheri | Mishra 1993 |
| AA 8463 | >41,900 | Mehtakheri | Mishra 1993 |
| A 6619 | 25,160±550 | Bhedaghat | Mishra and Rajaguru 1993 |

### *Nawarakheri*

The site Nawarakheri is situated on the left bank of the Narmada about 30 km downstream of Navdatoli (Fig. 1). The site of Nawarakheri is surrounded by gullies in the Late Pleistocene alluvium. Upper Palaeolithic artefacts are being exposed from the Pleistocene alluvium on the eastern side of the site. On the western side the gullies drain into the Deb River, a tributary of the Narmada, which joins the latter some 200 m to the west. On the other sides the gullies drain into the Narmada which is about 50 m away to the north of the site (Fig. 2).

The habitation deposit at Nawarakheri is about 10 cm thick and spread over about 25 sq.m, overlying black soil. This thin deposit indicates that the habitation was neither long nor intense. The cultural material (pottery, bones, stones) is found within the black soil up to a depth of 60 cm. This soil is absent from the surrounding areas and is preserved only in the habitation area. The cultural material may have been incorporated into the soil by the process of swelling and cracking which is a characteristic of black soils. The phosphate, carbon and nitrogen content of the soil samples from two profiles and the sand /silt, clay content of the same samples was determined and showed that both the cultural material (bones, pottery) and the chemical indicators of human activity are present in a low level within the soil horizon up to a depth of 60 cm (Table 2).

The features at the site include pits, hearths and rubble platforms. Rubble platforms occurred on the gully slopes, showing that the gullies predate the Chalcolithic period. A post-Chalcolithic fill which is seen within the gullies is being incised today.

The radiocarbon date from this site on charcoal associated with the cultural material is 1,910 ± 100 b.p. This date is very young for the Chalcolithic phase and it is difficult therefore to interpret.

### *Utawad*

This site, on the Sosar Nadi, a minor southerly tributary of the Narmada, is surrounded on all sides by gullies. The slopes of these gullies have the remains of a number of rubble platforms, showing that the gullies predate the Chalcolithic period. The habitational deposit overlies about 30 cm of black soil, preserved only in the habitational area. Pits and hearths are the major features of the site.

### *Pipri*

This is a second site on the Sosar Nadi, a few kilometres downstream of Utawad. It is closer both to the Narmada and the main channel of the Sosar. The site is similar in other respects to Utawad, except that the pre-Chalcolithic soil is only 20 cm thick.

### *Chilkalda*

This site is exposed in the road cutting on the right side of the Narmada River at the Rajghat bridge. A bell shaped pit can be seen in the section cutting into the Pleistocene silty

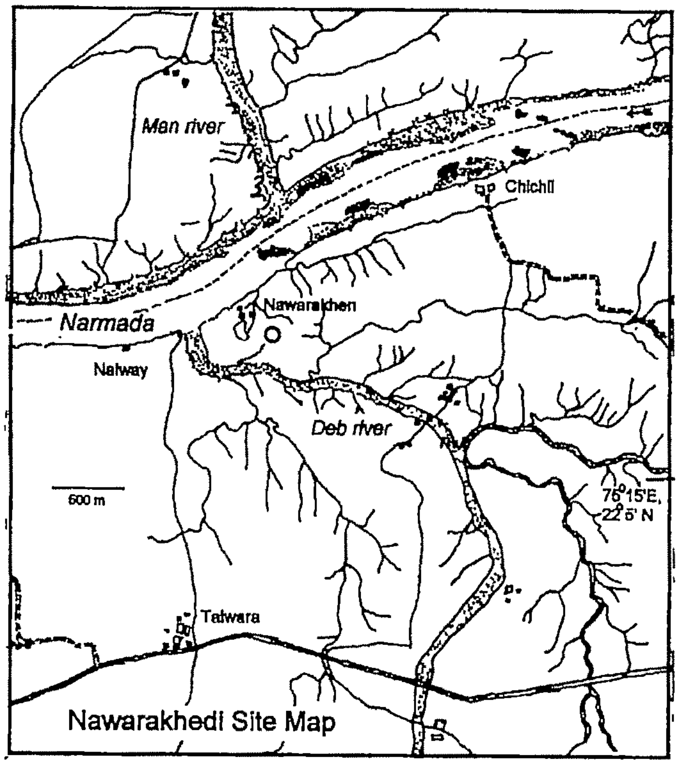

**Fig. 2:** Site map of Nawarakhedi

alluvium. The shape and size of the pit match those from the site of Pipri, excavated earlier. No soil is seen in this section, so the black soil was already stripped off at this location in the Chalcolithic period. About 1 m of Early Historical habitational deposit overlies the Chalcolithic levels (Mohanty 1998).

### *Khaparkhera*

The site of Khaparkhera is on the bank of the Narmada on a 1 km erosional terrace cut into the Pleistocene alluvium. A 7 m escarpment is a prominent feature of the local geomorphology about 1 km away from the Narmada on both sides of the river (Fig. 3). Between this sharp break and the river there is a flat area The Khaparkhera mound occupies the edge of this flat area (erosional terrace). A small channel drains this erosional terrace and accommodates the Narmada floodwaters. Therefore behind the site there is an accumulation of these flood deposits. Along the escarpment we located a number of Upper Palaeolithic lithic scatters which have been exposed by the erosion of the Late Pleistocene alluvium. A date of 15.6 kyr has been obtained for the Late Pleistocene alluvium at this locality. This alluvium has a well developed soil on it which is up to 2 m thick in the uneroded context. The erosion which left the 7 m scarp and the gullying post-dates 15.6 kyr and pre-dates the Chalcolithic occupation of the site.

The site of Khaparkhera is very extensive and the main occupation was in the Early Historical period after which the site was not occupied. The initial occupation on the site in the Early Historical period was on a prepared, rammed surface. In one trench on the periphery of the site, a collapsed roof was covered with flood silt in the last phase of occupation, just before the abandonment of the site. This is evidence for the site being affected by floods in the Early Historic period and coincides with the evidence from Navdatoli and Sakarghat.

Prior to the Early Historic occupation, though the site was occupied both during the Iron Age and Chalcolithic periods, this did not produce a "mound" deposit. During the Iron Age pits, including burials, were found. All these pits originate from the eroded surface of the Pleistocene alluvium. The Chalcolithic occupation was on the peripheries of the site, on the gullies incised into the Pleistocene silt. A brownish sediment was deposited during the Chalcolithic period, abutting the gully. The Chalcolithic material occurs in one horizon in this sediment.

### *Karondhia*

This site is a few kilometres downstream of Khaparkhera. At Karondhia the gullied Pleistocene silt has no soil cover. The Chalcolithic occupation consists of some pits whose outlines can be seen on the top surface, and the slopes of the gullies have rubble platforms. We are of the opinion that the Khaparkheda Chalcolithic would have been similar to Karondhia, except that at Khaparkhera the later occupation was extensive, while at Karondhia, only the Chalcolithic is present.

## Pleistocene Aggradation

The Late Pleistocene alluvium is well exposed throughout the region as the Narmada is presently incised into it. This alluvium is primarily fine grained, moderately calcareous, and forms steep cliffs. Units similar to this in the Son Valley have been identified as loess (Williams and Clarke 1995). Malik *et al.* (1999) have identified an aeolian component in a similar unit in Gujarat also. However, in the Narmada stretch, observation of the sedimentary structures shows clearly that most of this alluvium is fluvial in origin, with only occasional aeolian units. Fining upward sequences, calcrete/palaeosol horizons, fine sand units and small sandy channels can be seen. Rapid lateral variation is the norm. Some of the alluvium has traces of gypsum, which can be identified from the sulphurous smell given off when excavated. Fine laminations and bioturbation can be seen in some units also. Late Pleistocene gravels are seen at only a few localities, such as at Kherighat, Chirakhan, Beda River and Chota Barda (Mishra 1985).

The Late Pleistocene record therefore shows the Narmada in an aggradational mode, with a wide floodplain

**Table 2**: Sedimentological and chemical analysis of Trench C1 Quadrant 3, Nawarakhedi

| **Depth below Surface in cm** | **Munsell Colour** | **Gravel %** | **Sand %** | **Silt and Clay %** | **Organic Carbon %** | **Nitrogen %** | **Phosphate %** |
|---|---|---|---|---|---|---|---|
| 5 | 10YR 5/3 | 10.5 | 22.0 | 67.5 | 0.67 | 0.06 | 0.28 |
| 10 | 10YR5/3 | 19.0 | 12.5 | 66.5 | 0.68 | 0.06 | 0.27 |
| 15 | 10YR4/3 | 19.0 | 10.5 | 70.5 | 0.68 | 0.06 | 0.30 |
| 20 | 10YR 4/3 | 3.5 | 25.5 | 71.0 | 0.61 | 0.06 | 0.29 |
| 25 | 10YR 4/3 | 7.0 | 24.5 | 68.5 | 0.61 | 0.05 | 0.27 |
| 30 | 10YR 5/3 | 5.0 | 19.0 | 76.0 | 0.50 | 0.04 | 0.28 |
| 35 | 10YR 4/3 | 6.0 | 19.5 | 74.5 | 0.47 | 0.04 | 0.28 |
| 40 | 10YR 4/3 | 2.5 | 18.0 | 79.5 | 0.45 | 0.04 | 0.28 |
| 45 | 10YR 4/3 | 4.5 | 16.0 | 79.5 | 0.38 | 0.03 | 0.20 |
| 50 | 10YR 4/3 | 5.5 | 7.5 | 87.0 | 0.36 | 0.03 | 0.22 |
| 55 | 10YR 4/3 | 2.0 | 8.0 | 90.0 | 0.36 | 0.03 | 0.16 |
| 60 | 10YR 4/3 | 3.0 | 9.0 | 88.0 | 0.34 | 0.03 | 0.15 |
| 65 | 10YR 4/3 | 0.5 | 6.5 | 93.0 | 0.36 | 0.03 | 0.13 |
| 70 | 10YR 3/3 | 2.0 | 6.0 | 92.0 | 0.36 | 0.03 | 0.11 |
| 75 | 10YR 4/3 | 4.5 | 6.0 | 89.5 | 0.38 | 0.03 | 0.10 |
| 80 | 10YR 3/3 | 2.5 | 7.5 | 90.0 | 0.37 | 0.03 | 0.09 |
| 85 | 10YR 3/3 | 5.0 | 8.0 | 87.0 | | | |
| 90 | 10YR 3/3 | 2.5 | 8.5 | 89.0 | | | |
| 95 | 10YR 3/3 | 3.0 | 11.0 | 86.0 | | | |
| 100 | 10 YR 3/3 | 0.5 | 8.0 | 91.5 | | | |

and rapid deposition. The channel facies is less in comparison with the overbank facies. By contrast, at present the channel facies dominates and the floodplain is confined to a small area within the banks of the older alluvium (Gupta *et al.* 1999). This change in the Narmada is due to the change in climate. During the Late Pleistocene, the Narmada River was choked with sediment supplied from its large drainage area. However, the discharge was reduced resulting in an oversupply of sediment which was then deposited, building up an extensive floodplain. In the more arid parts of the Narmada Basin, it became an allochthonous river, with discharge sustained by rainfall in the more humid source zone. It is surprising that even in the Gujarat coastal plain, when sea levels were lower by over 100 m, the Narmada River was aggrading (Allchin *et al.* 1976). Offshore sediments also show that the peninsular rivers were not bringing sediments to the continental shelf during the Late Pleistocene (Hashimi and Nair 1986). This phase of aggradation in the Narmada therefore implies very different environmental conditions from those of today.

The Late Pleistocene age of this alluvium can be inferred from the presence of numerous Upper Palaeolithic sites and some radiocarbon dates. The Upper Palaeolithic artefacts are being found exposed from the silty alluvium. The stone tool technology was based on microblades obtained by the hard hammer technique from cores of siliceous rock. Quartzite was also utilized for making flake tools (Misxra 1993; Ghosh 1993). Ostrich eggshells are found at many sites and were used to make beads. Bivalves were utilized for food and charred examples are found at many sites. Red ochre and micaceous schist are also found at some sites and were probably used for decoration. Most of the sites also show burned sediments testifying to the use of fire. During this arid phase therefore human populations with a hunting and gathering mode of subsistence flourished on the nurturing banks of the Narmada.

Four radiocarbon dates have been obtained from this phase (Table 1). They are 30,000 and >+41,000 years at Mehtakheri, 25,160 at Dharampuri and 15,680 at

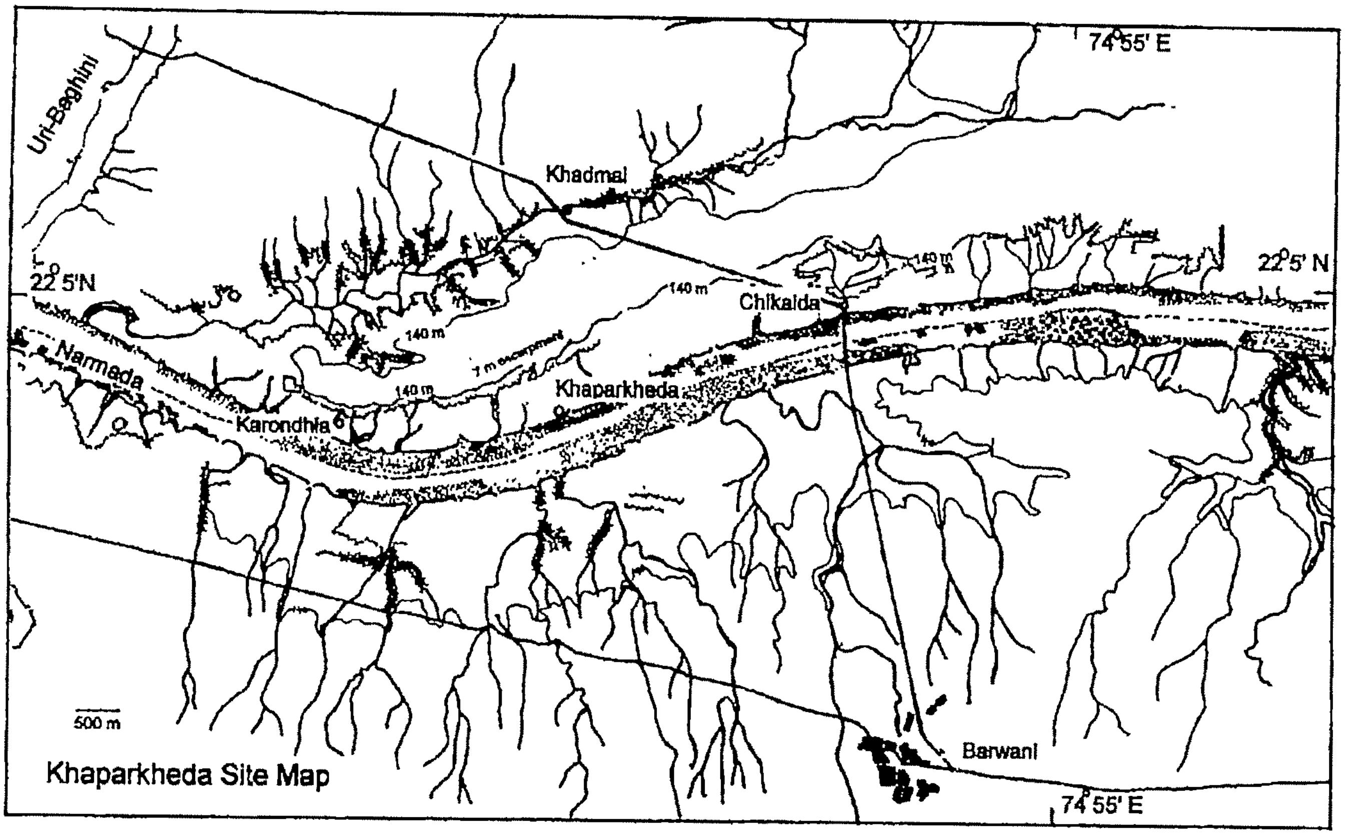

**Fig. 3**: Site map of Khaparkheda

Khaparkhera, all in association with the above mentioned sites. At Bhedaghat, near Jabalpur a date of 25,160 was obtained from a gravel containing a microlithic industry and unconformably overlying a gravel with Acheulian artefacts (Mishra and Rajaguru 1993). These dates show a range of more than 20.000 years and also show older dates from the upstream areas as compared with the downstream areas. This implies that further studies with the help of additional dates would make it possible to distinguish different phases within this period of aggradation.

### Early Holocene Incision and Soil Formation

The Late Pleistocene alluvium in the Narmada Valley is presently being incised by the Narmada River. On both sides of the river there are 10-25 m high "banks" which are made up of this older alluvium. Gupta *et al.* (1999) and Rajaguru *et al.* (1995) have characterized the Narmada as a "flood" controlled river. The large channel within the older alluvium accommodates the largest floods, which recur a few times in a century. Normal floods may only reach the base of the banks and the low flows occupy a small part of the channel. Erosion of the older alluvium near the Narmada channel has resulted in the development of "badlands". This erosion is not by tributaries joining the Narmada but by erosion during the large floods.

This gullying appears to be a contemporary process, as the gully walls have steep slopes and are poorly vegetated. However, we have observed at Nawarakheri, Pimpri, Utawad and Karondhia, the presence of Chalcolithic rubble platforms on the upper parts of these gully slopes, indicating that the gullying predates the Chalcolithic (2.5-3.5 kyr) and these rubble platforms have not been removed since. This indicates that the major part of the incision occurred before 4 kyr. The major features of the Narmada channel are therefore a product of the Early Holocene and are remarkably stable today, inspite of the present day Narmada floods being among the largest in the world.

The presence of an erosional terrace best preserved at Khaparkhera, but also present at many other localities along the Narmada (Nawarakheri, Dharampuri, Maheswar, Mehtakheri) implies that the erosion of the Late Pleistocene alluvium occurred in two phases. While the rubble platforms at Narwarakheri, Pipri, Utawad and Karondhia are on the upper gully surfaces, making it a possibility that the second erosional phase was post-Chalcolithic and the river was not incised to today's level during the

Chalcolithic, at Khaparkhera the Chalcolithic material is on the slopes of the lower gully. This makes it most likely that all the significant erosion of the Late Pleistocene alluvium is pre-Chalcolithic in age.

The other Early Holocene feature documented by the archaeological sites is the presence of a soil preserved below the Chalcolithic settlements. At Navdatoli the soil below the habitational mound is 1 m in thickness. At Nawarakheri a 1 m soil has archaeological material incorporated into it. The overlying habitational deposit is only 15-20 cm thick. This soil is not present except in the habitational area. At Pipri and Utawad also the black soil, thicker at Utawad than Pipri, is preserved only in the habitational area. At Khaparkhera, Chilkalda and Karondhia, which are on the banks of the Narmada there is no soil. This means that the soil had developed on the Late Pleistocene alluvium and had already been subjected to erosion by Chalcolithic times. The sites on the Narmada had already lost their soil cover before the Chalcolithic occupation, while the sites on the tributaries, such as Pipri, Utawad and Nawarakheri still had a soil cover. This cover has been stripped off from the surrounding area in the post-Chalcolithic period. Navdatoli, which is on the Narmada has seen the shifting of the channel away from the site. Being at a site of net deposition, the pre-Chalcolithic soil is preserved here.

### Floods During the Early Historic Period

The excavated Early Historic settlements of Navadatoli and Khaparkhera both have convincing evidence for large floods affecting the settlements during the Early Historic period. As settlements are located away from the effects of expected large floods, this shows that the magnitude of these floods was unusually large. Similar evidence has been obtained from the Sakarghat palaeoflood record, near Punasa about 100 km upstream of Maheshwar. At this site where only large floods can leave deposits, there are two series of flood deposits belonging to the Early Historical and Medieval periods respectively, with a period of few large floods intervening (Kale *et al.* 1996).

### Holocene Aggradation

Throughout the Nimar stretch of the Narmada, an inset fill is present. This fill is made up of sandy, silty alluvium, less calcareous and browner in colour than the Late Pleistocene fill. It is present at Navdatoli and Nawarakheri. At Navdatoli, it also post-dates the Early Historic period. At Pipri, Utawad, Karondhia and Chilkalda this unit is absent.

At Khaparkheda, the Chalcolithic material is found on a gully slope below the Early Holocene erosional terrace mentioned earlier. At this locality aggradation was contemporary with the Chalcolithic. This means that during a part of the Chalcolithic period aggradation was going on at some localities.

### Recent Incision

The post-Early Historic alluvial fill has been incised wherever it has been located. The timing of this incisional phase is uncertain, but it is possible that this process is currently continuing.

### Changes in the Archaeological Record

One of the most interesting features of the archaeological record is the change documented in the settlement/subsistence pattern over time. Permanent, large settlements are common in some periods and uncommon in others. Other features, such as building in brick, the presence of coins as well as inscriptions are more common in some periods than others. It has been suggested that the archaeologically "poor" periods were also periods of unfavourable environmental conditions (Dhavalikar 1993) although the data to link the two are still poor and this link is not accepted by all archaeologists (Paddayya 1994). One of "poor periods" is identified between the Chalcolithic and Early Historic. This period is well documented in western Maharashtra and especially at Nevasa (Sankalia *et al.* 1960) where a soil intervenes between the Chalcolithic and Early Historic deposits. This "sterile layer" is seen at a number of other sites, such as Prakashe in the Tapi Valley and Nagda in the Chambal Valley (Joshi and Deotare 1983). However at Navdatoli, Sankalia *et al.* (1958) have suggested that there is continuous occupation from the Chalcolithic to the Early Historic and no break was identified in the excavations. However, he does identify a break between the Early Historic and Medieval periods. At Khaparkhera also there is an intervening Iron Age phase, between the Chalcolithic and Early Historic. The late date for the "Chalcolithic" from Nawarakheri could also be because of the continuity between the Chalcolithic/Early Historic in this area. The gap between the Early Historical and Medieval periods is also well documented. Sharma (1987) has compiled the data from excavated sites in northern India and finds that during the period 400-900 A.D., most of the excavated sites show abandonment or decline. Building in brick and coinage become rare. It appears that this second poor archaeological period is more significant in the Narmada Valley than similiar earlier periods.

We would like to stress that at the moment the data are inadequate to make firm conclusions, especially on as complex a subject as human response to environmental changes. The limited available data appear to show that it is likely that the "gaps" in the archaeological record, although they do exist do not occur everywhere at the same time. Also, while human societies are extremely sensitive to changing environmental conditions, both the archaeological and environmental records must be studied independently and in detail. We also must keep in mind that human societies are also affected by many factors in addition to environmental ones.

Keeping in mind therefore the limited nature of the available data, both archaeological and environmental, two major features can be identified. Firstly, that compared with some other regions, the "gap" between the Chalcolithic and Early Historical periods is not obvious in the Nimar region. Secondly, the best documented "gap" period occurs after the Early Historical period. This period also has some evidence for fewer floods from the Sakarghat section as well as for the minor aggradation seen at Navdatoli and possibly elsewhere. Therefore there are some data to suggest that the reduction in settlements in the Narmada valley occurred during a period of relatively poor rainfall.

## Conclusions

The following sequence can be reconstructed from the available geoarchaeological data:-

1. **Late Pleistocene Aggradation:** The Narmada River was choked with an oversupply of fine grained sediment, overbank facies dominated the system and the alluvium accumulated salts. Aeolian processes reworked the fluvial material. This phase is dated between >30 kyr and 14 kyr and many Upper Palaeolithic sites are excellently preserved in the rapidly covered surfaces.
2. **Early Holocene Incision and Soil Formation**: Black soil developed on the alluvium beneath the settlements at Navdatoli, Nawarakheri, Pimpri and Utawad, while at Chilkalda, Khaparkheda and Karondhia it had already been eroded prior to 3.5 kyr. In some cases this soil is only preserved under the habitational deposit. Gullying into the Late Pleistocene alluvium is also pre-Chalcolithic (3.5 kyr) in age as can be seen by the presence of rubble platforms on the gully slopes at Nawarakheri, Pimpri, Utawad and Karondhia.
3. **Floods during the Early Historic Period**: At both Khaparkhera and Navdatoli where there is habitation during the Chalcolithic and Early Historic periods, there is evidence from the excavations for floods affecting human settlements during the Early Historical period (2 kyr). At Navdatoli a stupa was almost washed away, while at Khaparkhera a collapsed roof covered with fluvial sediment was found in the last phase of settlement. This complements the findings of Kale *et al.* (1996) for increased floods on the Narmada at the upstream site of Sakarghat during the early centuries of the Christian Era.
4. **Holocene Aggradation**: At most localities along the Narmada, a distinct Holocene alluvial fill can be distinguished from the Pleistocene fill. At Navdatoli this occurs between the river and the habitation mound and Sankalia has suggested that the river had shifted away from the site depositing this alluvium in post-Early Historical times. At Nawarakheri also the gullies around the site show a Holocene fill within these gullies containing artefacts and rubble derived from the site. This phase may represent a relatively arid period co-inciding with the reduced large floods at Sakarghat and smaller settlements in the Nimar region, after the Early Historical period.
5. **Recent Incision:** The post-Early Historic fill is presently incised at Nawarakheri and many other localities. Ely *et al.* (1996) have shown from palaeoflood studies in the upstream part of the Narmada, near Punasa that the floods of the last centuries are among the largest in the Holocene. This recent incision could be a response to these large floods.
6. **Reduction in Settlements after the Early Historic Period**: While both Navdatoli and Khaparkhera show almost continuous habitation from the Chalcolithic to the Early Historic periods, both the sites were abandoned later. A period of fewer large floods on the Narmada has been documented for the period from 400-900 AD from the palaeoflood studies at Sakarghat so that minor changes in climate might have had a major effect on human populations during the Historic period.

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# Studies in the Geomorphology, Quaternary Palaeoenvironments and Archaeology of the Vel River, a Tributary of the Bhima in Western Maharashtra

Sheila Mishra, Sonali Naik, Utpala Adhav, Sushama G. Deo and S.N. Rajaguru

Department of Archaeology
Deccan College
Pune 411 006

## Abstract

The Vel river is a tributary of the Bhima with most of its catchment in the semi-arid zone in Upland Western Maharashtra. It has preserved geomorphic and archaeological features throwing light on tectonic, climatic and archaeological history since the Neogene. In this paper we argue that denudational surfaces, high level gravels (HLG), weathered bedrock and the bedrock incised channel seen in the Vel basin around Talegaon Dhamdhere are relict features of the landscape. A series of aggradational episodes have been dated to around 10 kyr, 7 kyr, 2.5 kyr and 200 yr bp. The episodic aggradational activity of the Vel dates primarily to the Holocene while the trunk stream, the Bhima, was in an incisional mode during the same time period. We suggest here that this different behaviour during the same time is caused by different basin characteristics of the two rivers. Archaeological material is associated with all the aggradational episodes. Microlithic industries are associated with both the 10 and 7 kyr gravels, while Late Chalcolithic pottery is found at 2.5 kyr and a Maratha period temple at 200 yr bp.

## Introduction

Studies of the Vel have been carried out over the last three years. Repeated visits have been rewarded with many new insights, many of them applicable to the region as a whole.The Vel river, with a length of 64 km has its source about 15 km upstream of Peth, on the 700 m denudational surface. This surface forms the divide between the Bhima and Ghod rivers. The Vel River therefore lacks a catchment in the high rainfall Western Ghats zone, unlike the Bhima, Mula-Mutha and Indrayani (Fig. 1). Talegaon Dhamdhere is on the Vel, about 8 km from its confluence with the Bhima.

Some of the features of the Vel river are best explained by tectonics while others reflect the effects of climatic change. The present-day landscape has been formed over the last 60 myr years after the eruption of Deccan Trap near the Cretaceous Tertiary boundary .Tectonic forces play a major role in forming the landscape over long time scales while climatic change leaves its imprint over shorter time scales It is perhaps for this reason that geologists, for whom the Quaternary is a very short time period, stress the tectonic elements in the landscape, while archaeologists, for whom the Quaternary is a long time period stress climatic change as an important element. One group of features discussed, belongs to the Tertiary, and while relict, being formed under a climate different from the present, are none the less, primarily formed by tectonics. The second group of features all belong to the Holocene, and although exact palaeoclimatic interpretations are not possible with the present data, they reflect the frequent climatic changes of the Late Quaternary.

### Relict Features

One of the major findings of our work over the last decade is that many features of the present-day landscape are relict. By relict we mean not only that the features are old but also that they have been formed by processes different from those operating at present. This realization is based primarily on a single observation which has been discussed earlier (Mishra 1995; Mishra *et al.* 1993). This observation is that often gravels are found which overlie weathered bedrock or "*murrum*". Some of these gravels are at a "high level" and so they were called "High Level Gravels" by Foote (1878). However in some basins, these gravels are not at a high level. Nevertheless, because of the well established use of the term it is retained here. We have taken the most significant feature of the HLGs to be, not their high level, but the presence of "*murrum*" beneath them. This has important implications. The process of deep weathering of bedrock which produces *murrum*, requires time and also a humid tropical climate. This weathering must also post-date the gravel deposition as river channels

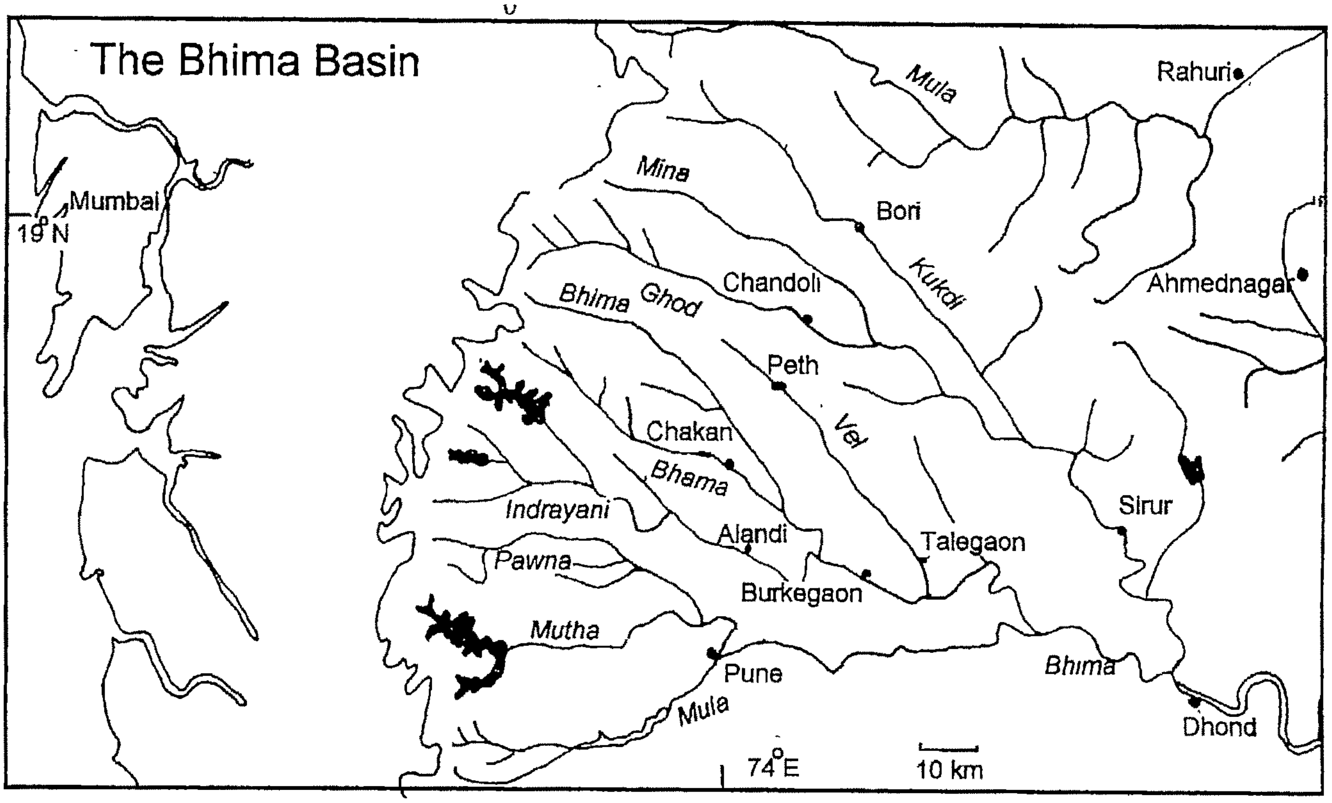

**Fig. 1**: The Bhima Basin

erode weathered material and so active channels occupy unweathered bedrock. Gravels with Early Acheulian artefacts at Laxmi Nala and Chirki near Nevasa and at Bori, overlie only slightly weathered bedrock, where the flute marks and smoothing of the bedrock by fluvial erosion is still preserved (Corvinus 1983). Mishra (1992) and Mishra *et al.* (1995) argue that these Early Acheulian industries are > 400 kyr and > 670 kyr and so probably of Lower Pleistocene age. This chain of reasoning therefore leds to the conclusion that the HLGs and the weathering that post-dates them belong to the pre-Quaternary period. The denudational surfaces on which the HLGs are found are therefore even older.

### *Denudational Surfaces*

The Deccan plateau is characterized by a "stepped" character. Flat surfaces at different elevations are separated from each other by "steps". These flat surfaces have been formed by denudational processes and have been separated from each other by episodic uplift. The Vel River originates on one of the most extensive of such surfaces (Dikshit 1970; Kale and Rajaguru 1988) at approx 700 amsl. In the Vel basin two lower surfaces at 600 amsl and 540 amsl are present. Around Talegaon, the 540 level forms an extensive surface while the divides are around 600 m. The 600 m level also forms a surface, well developed near Pune. The Vel river therefore traverses three surfaces (700 m, 600 m and 540 m) from its source to confluence. The HLGs are on the lowest surface and therefore all the surfaces pre-date the HLG.

### *High level gravels*

High level gravels are exposed in three localities around Talegaon. The first is near the Bhairava temple, where a small tributary joins the Vel (Loc 1, Fig. 2), the second is downstream of Talegaon (Loc 2, Fig. 2) and the third is along the road to Vittalwadi (Loc 3, Fig. 2). At the Bhairava temple 2 m of sandy pebbly gravel is exposed. This is cemented and cross bedding is preserved. It is about 4 m above the Vel bed level. The preservation of the sedimentary structures, and calcrete cement give this gravel a similiar appearance to Quaternary gravels such as those containing Acheulian artefacts at Bori and Nevasa. Most of the HLGs consist of well rounded exotic pebbles of resistant lithologies in a matrix of clay and carbonate, with little preservation of the original structures unlike the Vel HLGs. However the bedrock below the Vel HLGs is weathered to a depth of over 1 m unlike the bedrock below the Acheulian gravels. A lag of gravel is found scattered in the fields along the river. At Talegaon, downstream of the

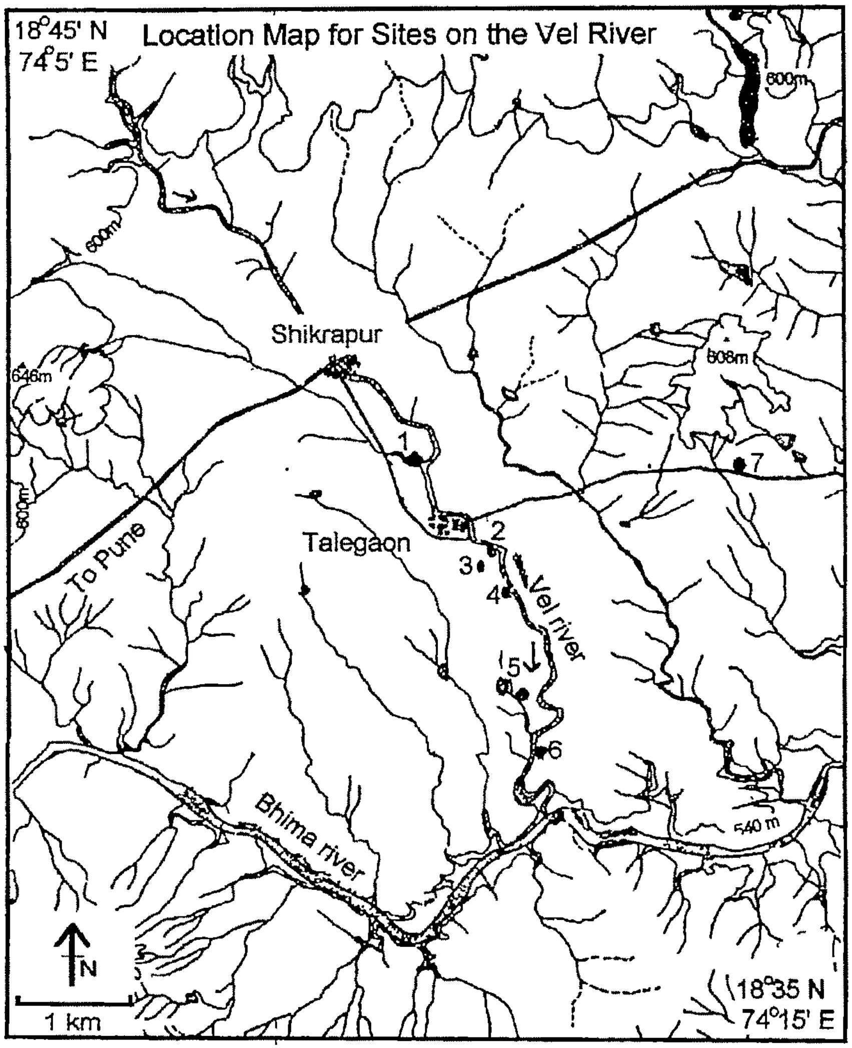

**Fig. 2**· Localities studied around Talegaon on the Vel River

village in the "bazar" locality, a 4 m thick gravel similar in character to that of the Bhairava temple is exposed on the left bank. For some stretch the gravel is exposed on both sides of the river. The bedrock below this gravel varies from compact, well jointed basalt to amydaloidal basalt. The weathering of the bedrock below the gravel varies with the bedrock lithology, with the jointed basalts more weathered than the amygdaloidal varieties. This gravel is also exposed along an untarred road running parallel to the river on the left side and has been exploited for building material, providing good exposures. The third exposure of gravel is on the right side (east) of the road to Vittalwadi from Talegaon. Here we did not observe any vertical exposure, but there is a lag of cobbly, pebbly gravel overlying bedrock. This gravel is richer in siliceous rocks and there are artefacts on the surface. It occupies the highest position in the locality and so indicates an inversion of relief.

### *Post high level gravel bedrock weathering*

The HLGs identified from Talegaon are associated with the youngest denudational surface. The gravels are fairly coarse, but unlike many HLGs, cobbles and boulders are rare, lithology is local and sedimentary structures, such as grading and cross bedding are preserved. The weathering of bedrock below the gravels is only about 1 m compared with over 5 m for many HLGs in the Godavari Valley. For this reason, it is likely that all the HLGs are not of the same age. The Vel HLGs appear to be younger than others observed by us in the Godavari (Joshi *et al.* 1980 ) and Tapi valleys (Mishra *et al.* 1993). Nevertheless, the weathering of bedrock below the gravels and the absence of any fossils or artefacts from these gravels leds us to consider them to be pre-Quaternary in age.

### *Fluvial incision of bedrock*

Near the Bhairav temple (Loc 1 on Fig. 2) the Vel has a rocky bed with a minor knickpoint. The bedrock has well developed potholes and flutemarks. After this knickpoint the river enters a stretch with a vertical bedrock bank on the left side. After Talegaon village it again enters a bedrock stretch with bedrock/HLG on either side. This bedrock incision shows the ungraded character of the Vel River even near its confluence. This bedrock incision may also be a relict feature related to rejuvenation when the present base level was established.

### *Implications of the relict features for the Quaternary*

The relict features discussed above, form the major landscape elements. The distribution and extent of HLGs is much greater than for any of the Quaternary gravels and the HLGs and weathered bedrock provide a ready supply of material for the Quaternary deposits. The reason for the dominance of the relict elements in the landscape is the ineffectiveness of present day processes to alter the landscape due to the semi-arid climate and tectonically stable landscape. The present day landscape therefore cannot be understood without understanding past processes.

While dating the various elements of the landscape is not possible, their relative chronology can be determined. The eruption of Deccan Trap close to the Cretaecous Tertiary boundary places a maximum age boundary, so that all the "events"/features post-date this important event. The denudational surfaces have developed by the continuing erosion of the Deccan Traps and the higher surfaces are older than the lower ones. A number of higher/older denudational surfaces are seen in addition to the ones in the Vel basin. The high level gravels are associated with the youngest of these denudational surfaces. The weathering of the gravels and the bedrock below them post-dates the gravel deposition. The bedrock channel incision post-dates the lastest denudational surface but in some cases appears to be prior to the Quaternary alluvium. The dating of the youngest "landscape" element to the Pre-Quaternary means that the other features are earlier

## Holocene aggradational episodes on the Vel River

In our explorations around Talegaon we were able to collect shells from two gravels for dating. In both the cases microliths were associated with the gravels from which the shells were collected. Our expectation, based on previous dates from Western Maharastra was that the gravels would date to the Late Pleistocene when many rivers were aggrading (Kale and Rajaguru 1987; Rajaguru and Kale 1986; Rajaguru *et al.* 1993; Sadakata *et al.* 1995). The results of the dating however showed that these gravels belong to the Holocene period (Table 1). The gravels dated were from Loc 3 ("Bazar" of Talegaon) and near Loc 2 (Bhairava temple) and dated to around 10 kyr and 7 kyr. In additional, minor episodes of aggradation during the Mid- and Late Holocene were associated with Late Chalcolithic pottery and the Maratha period Bhairava temple respectively.

### *Pleistocene/Holocene transitional period (10 kyr)*

Evidence for this time period came from Loc 2 (Bazar). On the right bank of the Vel, just downstream of Talegaon, an 8m section is seen (Fig. 3). This comprises 70 cm silt overlain by a pebbly gravel of about 2 m and then a silty sand with some sand lenses within it. This silty sand has a few micoliths and shells, but these were too few to collect for dating. Overlying the sand is a 1.5 m thick gravel. This gravel is horizontally exposed in a number of fields on the bank of the Vel. The surface gently rises with the gravel overlain by 1 m of silt and then 1 m of black soil. Calcrete nodules are being exposed from only one horizon in the silt and are part of a Bk horizon in the soil. Because the gravel has an extensive exposure on the surface many artefacts and shells could be collected from it. Two shell samples were collected from this gravel and dated separately. The first sample was of *Unio* bivalves associated with a part of the gravel which is mostly derived form the HLG exposed nearby and the second comprised gastropods associated with a more sandy facies of the same gravel. The dates are 10,390 ± 130 (BS 1427) for the gastropods and 9,420 ± 90 (BS 1228) for the bivalves. This 1000 year difference between the two species of molluscs within the same gravel might be partly due to the gravel itself having

**Table 1**: Radiocarbon dates from the Vel River near Talegaon Dhamdhere

| Lab No. | Sample No. | Material Dated | Age | Calibrated Age | 1σ Age Range |
|---|---|---|---|---|---|
| BS-1427 | TLG3 | Gastropods | 6,930±120 | 7,690 | 7890-7590 |
| BS-1228 | TLG1 | Bivalves | 9,420± 90 | 10,380 | 10,780-10,300 |
| BS-1427 | TLG2 | Gastropods | 10,390± 130 | 12,280 | 12,460-12,060 |

Calibration using the programme of Stuiver and Reimer (1993)

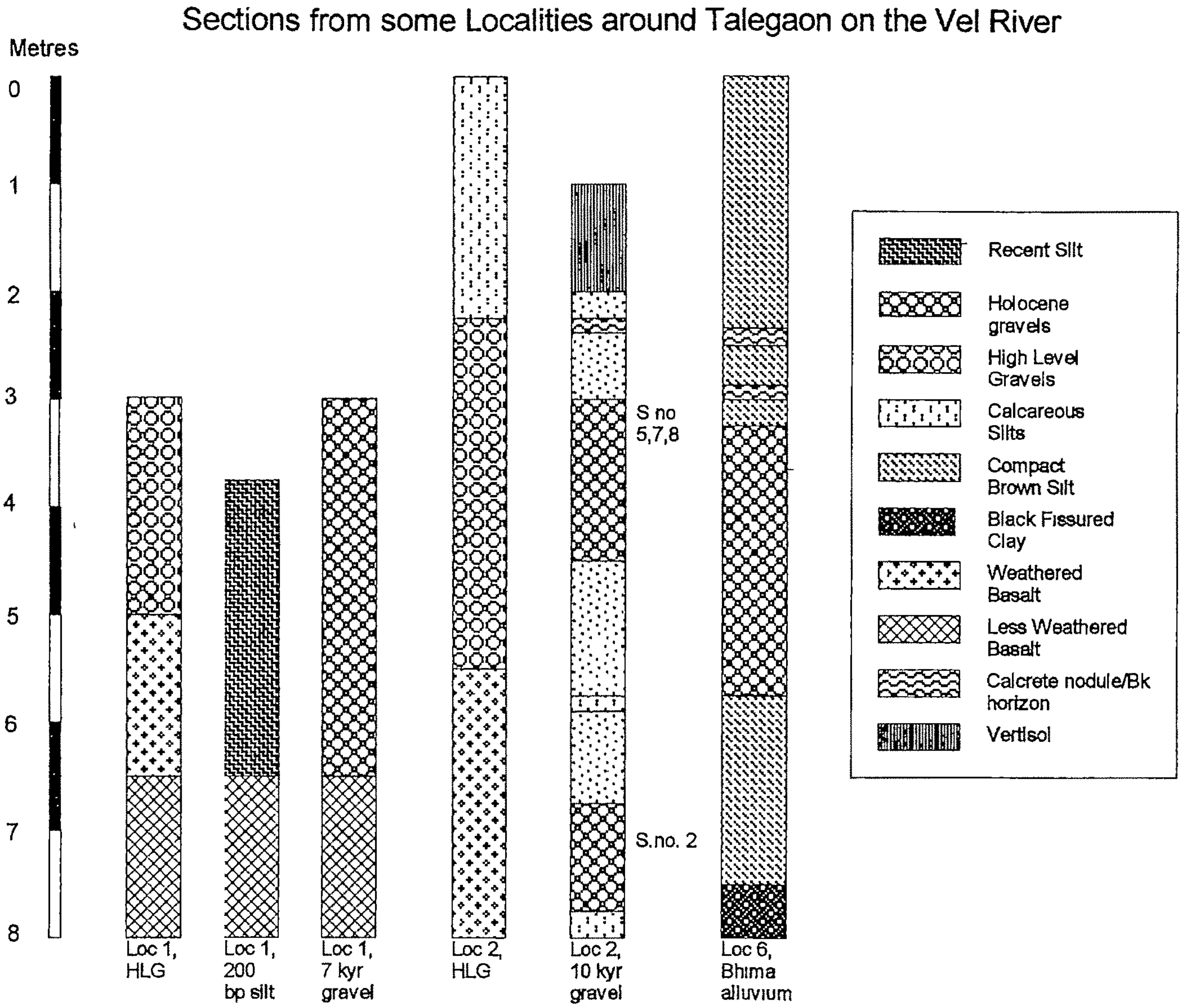

**Fig. 3**: Sections from some localities around Talegaon on the Vel River

existed for some length of time, and also due to different fractionation and reservoir effects of the two species. This time period is one of rapid change in the $CO_2$ of the atmosphere also, so that calibration of the radiocarbon dates at this time introduces more uncertainty into the dates (Table 1). However, the two dates do show that a significant aggradational phase on the Vel River occurred at the Pleistocene-Holocene transitional period (Mishra *et al.* 1998).

Interpretation of the climate during this phase is ambiguous. The local immature nature of the gravels implies a semi-arid climate, but whether this was more humid or arid relative to the present climate is more difficult to determine (i.e. as it is in a fairly arid zone, "relatively humid" might still be a semi-arid climate). It is possible that this river, having less discharge than the rivers originating in the Western Ghats, would become ephemeral during relatively arid phases and have little capacity to either deposit or erode. The depositional events might belong therefore to periods of relative humidity. The period 14-8 kyr was one of rapid climatic change and the dating itself cannot resolve the actual age of the event either to a well known arid phase or humid phase.

Some sedimentological studies of the gravels from this locality, as well as a study of the microliths collected from a 5 m x 5 m area of this gravel was undertaken for an M.A. thesis (Adav 1998; Adav and Deo 1998). The results of these studies show that the while the gravel from which the gastropods were collected shows normal distribution with a modal value in the 1-2 mm size range (making it a sandy gravel) the gravel from which the artefacts and bivalves were collected are bimodal with a coarse component mode in the 8-12 mm size range and the main mode in the 1-2 mm size range (Fig. 4) The coarse component is probably derived from the nearby exposure of HLG. It would appear that during this aggradation the presently exposed bedrock bed would have been buried. The artefact collection also has a primarily microlithic industry, but with occasional abraded/weathered flakes with Middle/Lower Palaeolithic affinities, which are also probably derived from the surface of the HLGs. Flakes from the gravel have a modal value of 1-2 cm and maximum sizes of 5 cm. Artefacts smaller than 1 cm are rare, but some were collected. The artefact assemblage is a microlithic blade industry. The artefacts are not abraded and flake to core ratio is high showing that although the context is from a gravel, the assemblage has not been severely modified by geological processes.

The well developed soil overlying the gravel is laterally fairly extensive. The thickness of this soil is over 1 m and a well developed Bk horizon is seen. The dating of this gravel therefore also gives us a maximum age for the soil development.

### *Early Holocene aggradation (7 kyr)*

Upstream of Talegaon village there is a minor knickpoint. Upstream of this knickpoint an alluvial fill is seen. Most of this fill comprises calcareous silts and pebbly cobbly gravels in which no artefacts or other dateable material could be found. A small sandy gravel, similar in characters to that from Loc 1 which contains the gastropods is seen. This forms a 4-5 m fill inset to the older alluvial deposits. Microliths were found in this gravel. It is also rich in gastropods which were extracted for dating. These gastropods were dated to 6,930 ± 120 b.p. (BS 1427). This dating shows that the two gravels, although they have similar

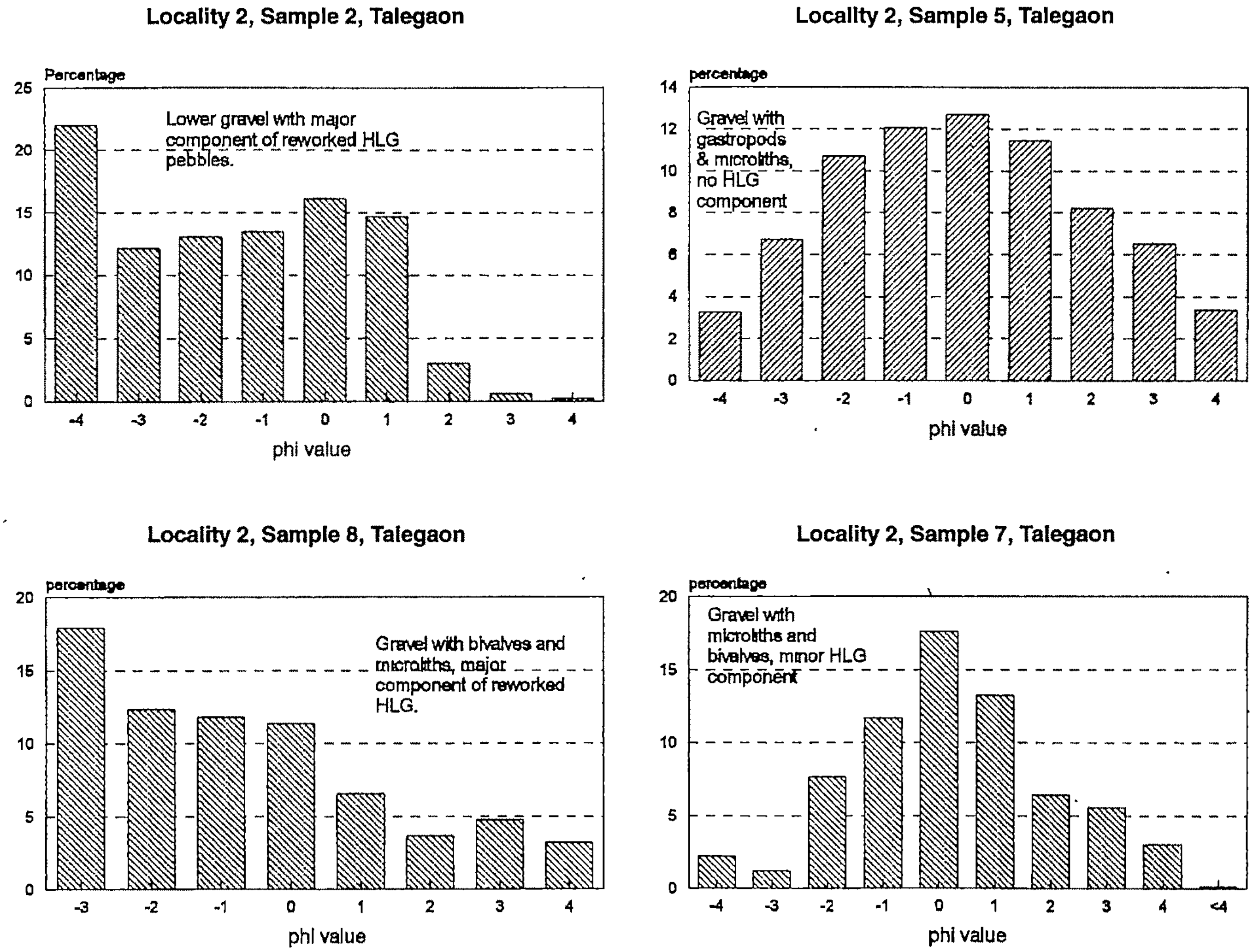

**Fig. 4**: Size distributions for gravel samples from Locality 2

characters do not belong to the same time period. The gravel near Bhairava temple therefore belongs to a later episode of aggradation compared with the one from the Talegaon Bazar locality.

*Mid-Holocene aggradation (2.5 kyr)*

Chalcolithic pottery was found at Loc 4 (Fig. 2). This was earlier reported by Naik and Mishra (1997). This Chalcolithic pottery was collected from a 20 cm colluvial gravel sandwiched between silty clay which is exposed at the margins of the zone affected by the Vel in flood. The pottery therefore was incorporated into a colluvial deposit, probably shortly after the abandonment of the site. This colluviation implies an unstable land surface, probably denuded of vegetation. The total extent of this site is less than 3 m x 3 m, and so is quite unlike any other Chalcolithic site so far reported. The pottery assemblage is similar to that collected from the nearby site of Sheriwadi (Naik and Mishra 1997) and has some similarities to that of Theur reported by S.R. Rao (*IAR* 1972/3: 35). It has a link with the Chalcolithic in that one ware is related to Jorwe ware, but has a coarser fabric, slightly different slip and cruder paintings. The associated wares are black and red ware with abundant graffiti marks and the red slipped ware which is also found in the Early Historic period. This pottery assemblage obviously has affinities to both the Chalcolithic and Early Historical assemblages and Naik and Mishra place it in the transitional period between the two phases. This probably belongs to the so-called "gap" period identified from western Maharastra during this time (2200-1800 b.p., 1200-800 B.C.). The landscape instability indicated by this site provides limited evidence for relative aridity during that period.

*Late Holocene aggradation (200 yrs bp)*

The Bhairava temple — about 200 years old — is built on bedrock near the HLG exposure. The temple is now about 100 m away from the river. The intervening area is filled with a very recent appearing brown silt. Quite a bit of pottery can be seen in this brown silt, both on the surface and in the section exposed on the river bank. This appears to be deposited after the construction of the temple which might have been on the bank of the river when it was first built. While this aggradation is minor and may have no climatic significance, similar fills have been observed at a number of other sites in Maharashtra such as Songaon on the Karha-Nira confluence and Navgaon on the Virabhadra River near its confluence with the Godavari near Paithan.

## Late Pleistocene Aggradation of the Bhima

This study has been mainly concerned with the Vel alluvium. At Loc 5 (Fig. 2) about 1 km from the Bhima a small man-made pond has exposed a thick black fissured clay. This fissured clay has well developed calcrete nodules. A few microliths were collected from this locality. This alluvium is most probably the older alluvium of the Bhima. The presence of microliths also indicates that at least some of it probably belongs to the Late Pleistocene. At Loc 6 (Fig. 2), an almost 10 m thick section of brown clays sandwiching a 2 m gravel was observed (Fig. 3). This gravel also had a few microliths. A few bivalves were found but they were fragile and weathered compared to those from Loc 2 and we could not collect enough for radiocarbon dating. The Bhima alluvium extends slightly more than 1 km from the present channel. It is predominantly clayey and silty with occasional gravel lenses, while the Vel alluvium is predominantly sandy and gravelly. None of the Bhima alluvium has been dated at this locality, but in general the dates for the alluvium in western Maharashtra belong to the Late Pleistocene. Prior to our study, only one Early Holocene date had been obtained for the Bhima Basin. This was from Akoni (Kale and Rajaguru 1986), on a small tributary of the Bhima in the downstream region Therefore while we cannot be categorial that the Bhima and Vel alluvium at Talegaon are of different ages, it is suggestive that all the dates on the Vel alluvium are Holocene, while all dates on the Bhima alluvium are Pleistocene. The only other Early Holocene date is also from the alluvium of a Bhima tributary. This different response of the fluvial system to climatic change is due to the different amount of rainfall in the catchment zones and also the different sizes of the basins. The Vel River has less rainfall and a smaller catchment than the Bhima and would respond to relative aridity by becoming more ephemeral and would have little capacity to deposit sediment in the absence of sufficient discharge. During relatively humid phases the abundant relict sediment/weathered material would be locally deposited and reworked. The Bhima River, on the other hand would be able to erode material from its basin during relatively humid periods and would aggrade during relatively arid periods when the sediment to discharge ratio increased. While this complex fluvial response to climatic change complicates straightforward climatic interpretations, it means that the fluvial record missing in one part of the system is present in another part of the system. This has provided us a glimpse into the Early Holocene story of western Maharashtra which was missing earlier.

## Important Implications of the Study

It is only in the last few years that the importance of the Tertiary in the present landscape has been realized. HLGs are part of the regolithic cover on the lower dedunational surfaces (700 m-540 m). This regolith has supplied the Quaternary fluval systems which are characterized by local reworking of the Tertiary material.

The Vel appears to have responded differently than the Bhima to changing climate during the Late Quaternary.

While the Bhima and Ghod were aggrading during the phase of Late Quaternary arid climate, all the units on the Vel which could be dated belong to the Holocene. The only other Holocene date from the Bhima basin also is from a small tributary, the Nandi, at Akoni (Kale and Rajaguru 1986).

The microliths from the Vel have been dated to 7 and 10 kyr, providing new evidence for human adaptations during this time period. This is just a begining, and as yet little beyond the presence of a microlithic industry during that time has been established. However further archaeological work will be a priority as it is during this time that man transformed his subsistence from hunting gathering to plant and animal domestication.

The Chalcolithic site of Talegaon belongs to a period for which no archaeological evidence was known earlier. It also provides some corroborating evidence for increased aridity during that period.

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# Geoarchaeology of the Acheulian Workshop at Isampur, Hunsgi Valley, Karnataka

K. Paddayya, Richa Jhaldiyal and Michael D. Petraglia[1]

Department of Archaeology
Deccan College
Pune 411006

1 Department of Anthropology
National Museum of Natural History
Smithsonian Institution
Washington, D.C. 20560
U.S.A.

## Abstract

This paper presents an up-to-date account of 3 seasons of field work (1997, 1998, 1999) conducted at the Acheulian site near Isampur in the Hunsgi Valley. The results of this field research comprising explorations, mapping of surface features, contour survey and excavations include: a) identification of a shallow palaeodrainage tract on the western edge of which the site is located; b) recognition of variability in the preservational contexts of the Acheulian level ranging from fluvially rearranged ones through ones partially altered by past and contemporary land modification processes to *in situ* or primary contexts; c) a comprehensive understanding of the lithic reduction sequences; and d) recognition for the first time of the stratigraphical context of the Middle Palaeolithic culture of the region.

## Introduction

The Hunsgi and Baichbal valleys of Karnataka constitute one of the densest concentrations of Lower Palaeolithic sites in the Old World (Paddayya 1982, 1987a, 1989). In two of their previous articles Paddayya and Petraglia (1997,1998) presented a brief account of the results of their field investigations conducted at the Lower Palaeolithic site of Isampur in the Hunsgi Valley. This site was discovered by Paddayya in 1983 during his comprehensive research project on the Stone Age sites of the Hunsgi and Baichbal valleys (Fig. 1). As part of their field studies dealing with the formation processes of the Acheulian sites of the region (Paddayya and Petraglia 1993,1995; Jhaldiyal 1998) the present authors revisited some of the type sites in November 1994 to collect fresh geomorphological and stratigraphical data.

During these field studies they recognised additional palaeogeographic and cultural features at one of the Acheulian localities near Isampur (Locality II). Several dozen artefacts of limestone were found on the valley floor which was covered in patches with a black/brown silt deposit measuring from 15 cm to more than 1 m in thickness. The discrete occurrence of the cultural material and its fresh physical condition suggested that the site was preserved in a non-transported context. It was also realised that the site witnessed a considerable amount of lithic production activity, because many limestone cores in various stages of working, hammerstones made on harder rocks like quartzite, Intertrappean chert and basalt, and a large amount of debitage were found scattered all over the locality. In short, both from the preservation and cultural points of view, it was felt that this site possessed certain novel features not noticed at the other Acheulian localities discovered by Paddayya in the Hunsgi and Baichbal valleys, including the ones excavated by him at Hunsgi and Yediyapur in 1975-76 and 1986, respectively (Paddayya 1977, 1979, 1987b).

Against this background further field investigations were conducted at the site in March 1997. We prepared a regular site map, showing the scatter of cultural material on the surface and its spatial extent. One dozen test pits (1 $m^2$) were also dug in order to ascertain the nature and extent of the Acheulian horizon and its sedimentary/stratigraphical context. Some of these pits did reveal undisturbed cultural material beneath the black/brown silt deposit. Two of these test pits were enlarged into regular trenches (Trenches 1 and 2). Trench 1 covered an area of 3 $m^2$ (2 x 1 m) and Trench 2 covered an area of 15 $m^2$ (5 x 3 m). Beneath the top 10-15 cm of thick clayey soil in Trench 2 a number of limestone blocks and artefacts were exposed. Their relatively loose and aggregated condition suggested that much of the material lies in a secondary context and represents the redeposited portion of material scoured out by water action in recent times from other parts of the site.

Trench 1 gave a more significant body of evidence. Here beneath 10-15 cm of thick blackish sticky silt, a thin (5 to 8 cm) colluvial gravel lens consisting of nodules of Intertrappean chert and flake artefacts of Middle

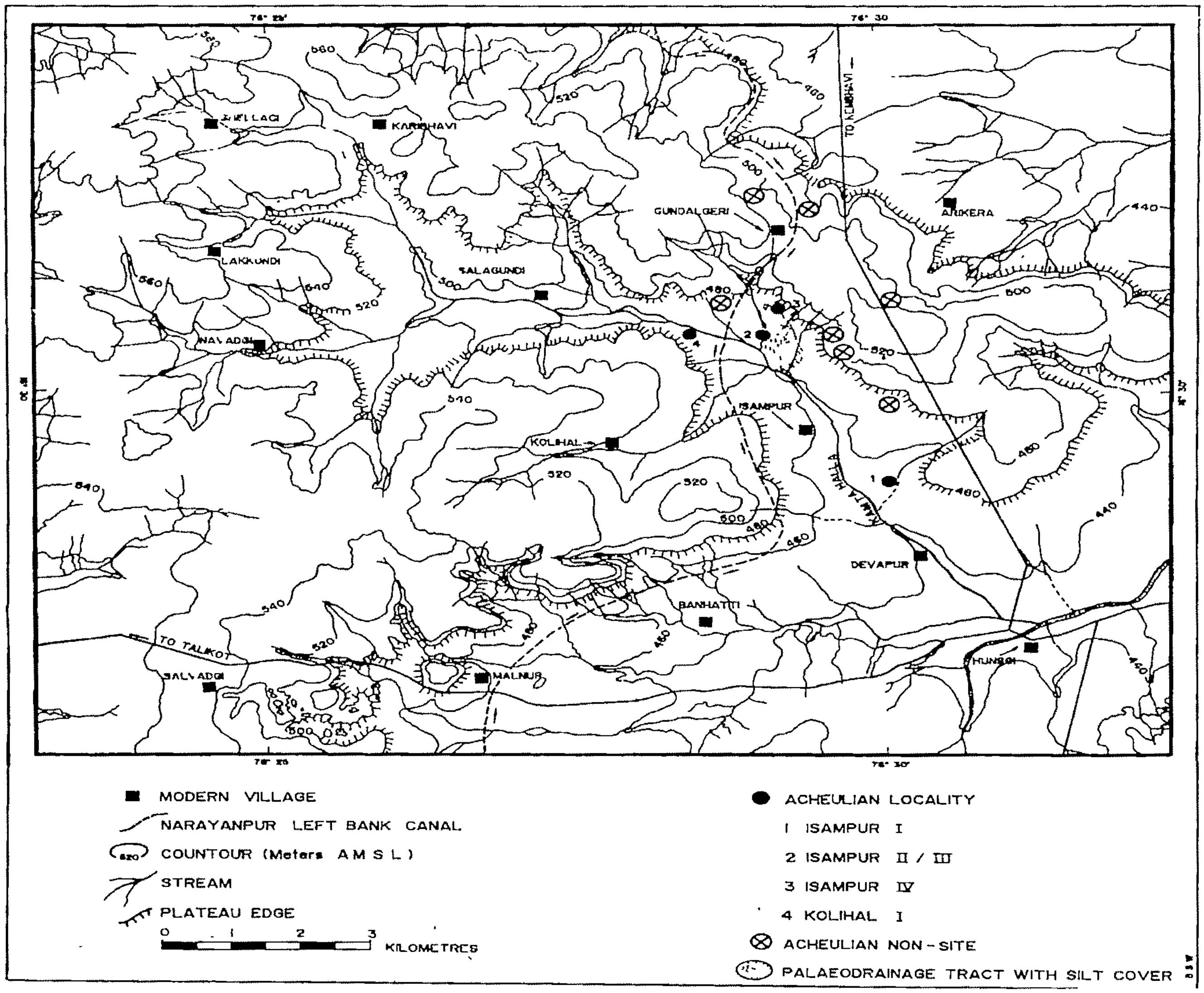

**Fig. 1**: Isampur sub-valley showing the distribution of Acheulian localities

Palaeolithic character were found. The Acheulian cultural material was found underneath the gravel lens. This horizon was about 20 cm thick, lay directly on the weathered limestone surface and yielded a total of 145 artefacts. This cultural assemblage showed features quite different from those of Trench 2 material. First, the artefacts were found in mint condition; their surfaces and edges were fresh and showed no signs of abrasion or smoothening such as would result from spatial displacement and rearrangement by water. Secondly, most of the artefacts were found lying on their flat surfaces, thereby indicating that they were in their original positions. Thirdly, unlike the loose character of the assemblage from Trench 2, these artefacts were embedded in a matrix of calcareous brownish silt.

Due to the encouraging results provided by these fresh field studies the Isampur site emerged as a welcome addition to the various other types of Lower Palaeolithic sites already known from the Hunsgi and Baichbal valleys. It was felt that this site, as against other Acheulian localities classified into functional classes such as occupation sites, food-processing sites and single-episode activity sites, is a regular workshop located on the raw material source itself containing limestone blocks of suitable shapes and sizes. It was realised that the emphasis here was on the production of various types of flake blanks meant for manufacture into regular tool types. From the large proportion of cores and debitage but the small number of finished tools it was felt that this site probably served as a localised centre for raw material extraction and tool-making, and that from here flake blanks and finished tools were carried away to the nearby occupation and food extraction and processing localities. In view of its special importance it was felt necessary to carry out a more detailed excavation at the site.

Accordingly, additional field investigations were taken up at the site during the months of February and March 1998. These included fresh studies of cultural as well as landscape features exposed on the surface of the site and in the area around it, and a more detailed excavation of the Stone Age site. In addition to a preliminary contour survey of the site and the surrounding region, the entire Stone Age site was gridded and all the cultural material and terrain features were mapped afresh. Twenty additional test pits (1 $m^2$) were dug. Trench 1 was extended to cover an additional area of 21 $m^2$. A new trench (Trench 3) was also excavated.

The aim of these field studies was four-fold: 1) to reconstruct the palaeolandscape of the site area and identify the factors which favoured its selection by hominids; 2) to ascertain the sedimentary and stratigraphical contexts of the Acheulian level; 3) to detect the ancient as well as more recent (natural and anthropogenic) processes which served to preserve or modify the cultural material; and 4) to obtain further insights into the lithic production sequences adopted by the hominids. These fresh field studies enabled us to realise most of the above aims. Additionally, a Middle Palaeolithic horizon was also found in the excavation.

## Site, Setting and Palaeolandscape

The village of Isampur (16° 30'N; 76° 29' E) is located in the northwestern part of the Hunsgi Valley and consists of a narrow sub-valley (Fig. 1), measuring about 12 km in length (east-west) and 1 to 3 km in width (north-south) (for details see Paddayya and Petraglia 1997). The head of the Isampur Valley is in the west and is formed by badlands carved into the Deccan Trap plateau. It is flanked by shale-limestone plateaus on the southern and northern sides. The eastern boundary of the valley is formed by a southward extending spur of the northern plateau. As governed by the contours of this spur, Isampur Valley takes a southerly bend near the village of Isampur and merges with the Hunsgi Valley after a distance of 5 km. Like the parent Hunsgi Valley, Isampur Valley is erosional in origin and has been sculpted by a long drawn out process of backwearing of the surrounding uplands. The valley floor has an elevation of 500-520 m above mean sea level in the west and slopes down to 450 m above mean sea level where it opens out into the larger Hunsgi Valley (Fig. 2A).

The Isampur Valley is drained by a seasonal nala locally known as the Kamta Halla. This is a fourth order stream originating in the badlands and flows in an easterly direction for a distance of 13 km and then, in tune with the southerly bend of the valley near Isampur, takes a southerly course and joins the Hunsgi Nala after a distance of 6.5 km. The drainage network of the valley is made up of 85 streams (68 belonging to the first order, 14 to the second order and 3 to the third order), which originate on the uplands enclosing the valley on all sides. The total catchment area of this stream is about 80 $km^2$.

The Acheulian site lies about 150 m from the left bank of the Kamta Halla where it takes a southerly bend. The site forms part of the limestone surface of the valley floor (460 m AMSL) and lies about three-quarters of a kilometre from the base of the plateau strip defining the eastern side of the valley. It is located at the confluence of two shallow watercourses draining the pediment surface. One of these (a third order stream) originates on the northern plateau near the village of Gundalgera and the second (a first order stream) originates on the eastern upland. The extensive soil quarrying by the Irrigation Department from 1982 to 1983 (for making the embankment of a major canal called the Narayanpur Left Bank Canal located about 1 km to the west of the site) led to some changes in the courses of these streams. It is perhaps important to note that even the pre-1982 channelisation of the watercourses draining the pediment surface basically owe their origin to the activity of modern farmers who raise bunds along their farmland strips in order to divert water flow and thus prevent soil erosion. It is almost certain that in pre-modern times, when farming activity was limited, the discharge on the valley floor took the form of broad sheetflows.

The site occupies three-quarters of a hectare (90 m north-south and 80 m east-west) (Fig. 3). A part of this area is farmland (owned by Shri Aminappa Harnal) and the rest is formed by the shallow bed of the watercourse descending from the northern plateau. The farmland portion is covered with black/brown silt ranging in thickness from 10/20 cm to 1.2 m. Much of this silt was quarried away by the Irrigation Department in 1981-82 to raise the embankment of the major irrigation canal mentioned above, leaving behind remnant patches varying in thickness from 20 or 30 cm to 75 cm. Close to the northeastern corner of the site there is a silt patch measuring 3 m in thickness.

In that part of the site which lies in the watercourse the Stone Age cultural material and the underlying limestone bed are exposed due to stripping of the silt cover by quarrying and erosion. Much of this area is now covered with 10 to 20 cm thick blackish sticky clay of more recent times, supporting scrub jungle vegetation (mostly thick grasses and plants belonging to *Cassia* and *Acacia* species).

The watercourse, which has exposed part of the Acheulian occupation level is narrow on the northern side due to the preparation of field bunds. As against this, the southern portion of the watercourse is ill-defined and

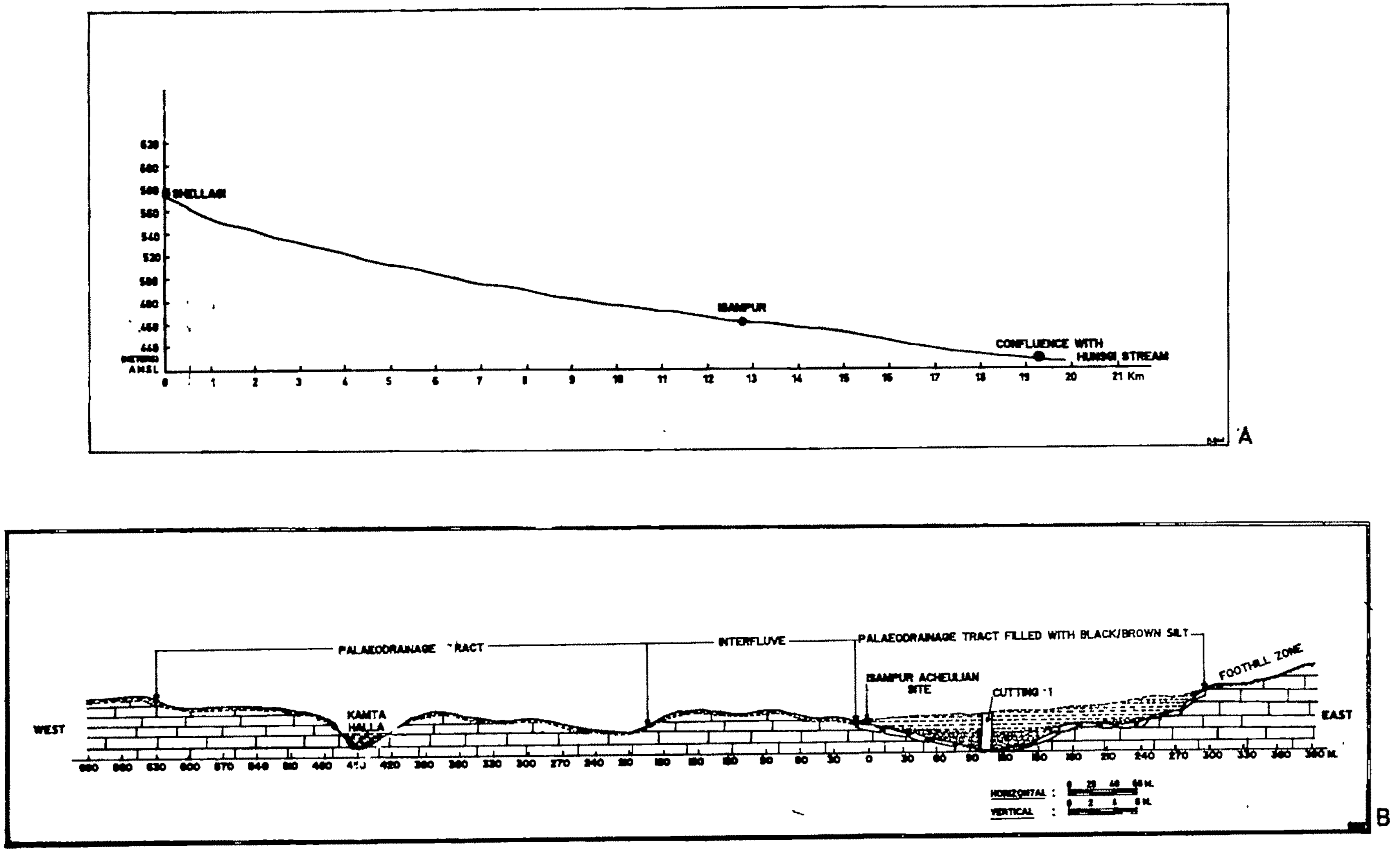

Fig. 2: A: longitudinal profile of the Kamta halla, which also holds good for the Isampur valley floor gradient; B: topographic transect (east-west) of Isampur Valley showing the Acheulian site in relation to the eroded limestone bedrock and palaeodrainage tract filled up with black/brown silt

shallow and occupies a broader area. It is also lower in elevation by about a metre as compared to the upper part of the watercourse as a result of which some patches of the lower portion of the site witnessed scouring by water action; this site modification took place in more recent times after soil quarrying by the Irrigation Department.

Examination of the rain gullies, field bunds and cuttings where soil was quarried brought to light the existence of a shallow and large eroded tract on the limestone surface. This tract lies between the Stone Age site and the limestone plateau strip defining the eastern margin of Isampur Valley. It is 1.5 km long (north-south) and 200 to 300 m wide (east-west). This shallow tract resulted from the erosional activity of drainage ancestral to present-day watercourses descending from the plateaus on the northern and eastern sides (Fig. 2B). In fact, it should be mentioned here that this palaeodrainage tract forms part of a network of shallow fluves and low interfluves making up the floors of Hunsgi and Baichbal basins. These fluves and interfluves are the products of a long process of backwearing of plateaus and impart a gently undulating form to the basin floor. This distinct topographical form is essentially due to the horizontally bedded character of shales and limestones and their susceptibility to solution weathering.

The Acheulian site at Isampur lies on the western edge of the palaeodrainage tract which would have served as a major source of water to the hominids. This setting of the site by the side of a waterbody is confirmed by the finding of a few fossilized shell fragments of the pond turtle belonging to the genus *Clemmys* in one of the excavated trenches. In Late Pleistocene times the drainage tract was filled up with a 3 to 4 m thick body of black/brown sediment.

Our surface studies including digging of trial pits revealed that the selection of this locality by the hominids was largely governed by a plentiful and on-the-spot occurrence of raw material for chipping comprising hard and highly siliceous limestone blocks of suitable sizes and shapes, resulting from the weathering of the limestone bed forming part of the valley floor. These blocks have flat surfaces and are of rectangular, squarish and triangular shapes. In size, they measure from 30 to 40 cm in length and from 10 to 15 cm in thickness. The sheltered topography of the valley, low heights (30 to 40 m above the valley floor) and flat surfaces of the uplands, which facilitated free movement of the hominids in their hunting-gathering activities, and the availability of a variety of wild plant and animal foods, as suggested by ethnobotanical evidence (Paddayya 1982: 71) in addition to the discovery of small quantities of fossil fauna in the Isampur excavation and at other sites in the Hunsgi and Baichbal valleys (Paddayya 1985, 1989), were the other favourable factors which influenced the selection of this site by the hominids (for some major studies of hominid behavioural patterns, see Potts 1988; Oliver *et al.* 1994; Isaac and Isaac 1997).

### Sedimentary Context

Our enquiries with the local farmers and inspection of the sections preserved in rain gullies and cuttings of the quarried area and the study of sediments found in test pits and excavated trenches made it possible to understand the nature and origin of the sedimentary record preserved in the area as well as the stratigraphical position of the Stone Age cultural material. At a few places in the quarried area covering the palaeodrainage tract a 25 cm thick conglomerate horizon was found resting on the eroded surface of the limestone bed. It consisted of angular limestone blocks bearing kankar or calcrete-like encrustation. This encrustation represents a precipitate formed in a pool-like environment containing carbonate-rich waters. This was overlain by a 3 to 4 m thick silt deposit; its upper half was blackish in colour, while the lower half was made up of brownish sediment. One of the interpretations is that the brown and black silts belong to the same sedimentary unit and that the brown colour represents a prolonged period of leaching of carbonates from the upper levels. An alternate and more likely explanation is that the two silts represent different sedimentary cycles. Laboratory studies are underway to understand their genesis.

The sediment cover in the area occupied by the Stone Age site is much less. This is in conformity with the elevated nature of the limestone surface. The kankar conglomerate horizon found in the palaeodrainage tract is absent here. The Acheulian cultural level lies directly on the limestone surface; its matrix is formed by calcareous brown silt measuring about 20 cm in thickness. It is in turn overlain by a thin (5 to 8 cm thick) colluvial gravel lens yielding Middle Palaeolithic tools made mainly of Intertrappean chert. (In this connection it may be noted that Foote (1876: 189-9) reported an extensive and thick Intertrappean chert bed between the villages of Shellagi and Pirapur located in the headward region of the Isampur valley.) The silt cover overlying the gravel lens is preserved to varying depths due to quarrying and erosion; its thickness varies from 10/15 cm ≥ 1 m. In one of the cuttings made on the western side of the site a 1.2 m thick compact silt deposit (brown silt below, overlain by black silt) was found overlying the Acheulian level.

This silt deposit, covering the valley floor and supporting crops like sorghum, cotton, groundnut and sunflower, is an ungraded and immature sediment rich in carbonate nodules. It is also characterised by the presence of angular to subangular pieces of basalt and chert derived from the Deccan Trap formations capping the uplands and quartzite pebbles and cobbles derived from pre-Trappean conglomerate beds occurring on the northern and eastern uplands. The particle size analysis has revealed that the sediments are essentially clayey silts with high $CaCO_3$ content. The deposit obviously did not result from a single episode of sedimentation but represents a series of depositional episodes. It is possible that under conditions of landscape stability soil formation took place on these silts but so far no such true soil profiles could be identified due to disturbances created by intensive cultivation and quarrying activities.

Microscopic analysis of the silt has revealed the presence of very angular pieces of quartz and occasional pieces of biotite. These minerals indicate that the sediments underwent short distance transportation. The deposits were derived mainly from the weathered products of the Traps forming the mantle of uplands flanking the Isampur Valley on its northern and eastern sides, and were deposited on the valley floor by an interplay of colluvial and fluvial processes. This interpretation is borne out by the presence of basalt pieces and Intertrappean chert nodules in the silts.

**Excavation: 1998**

The surface distribution of cultural material on the site and the data from 30 trial pits dug in 1997 and 1998 revealed that the maximum concentration of cultural material is in the watercourse portion where the silt cover was exposed by quarrying activity and subsequent erosion. Three trenches were excavated in this part of the site — Trench 2 in 1997, Trench 1 in 1997 and 1998, and Trench 3 in 1998.

Trench 1 lay at the junction of the watercourse and the farmland on its eastern side. An area of 3 m² was excavated in March 1997. In February and March 1998 this trench was extended to cover an additional area of 21 m². It measured 6 m in a NW and SE direction and 4 m in a NE and SW direction. For want of time it could only be excavated up to a depth of 40 cm only below surface i.e. the upper part of the Acheulian horizon (Table 1).

Trench 2 (5 x 3 m) lay on an island-like patch of land forming part of the bed of the watercourse and revealed the stratigraphy shown in Table 2.

Trench 3 (Table 3) was located between the water-course and the farmland on its western side. It measured 7 m (east-west) and 6 m (north-south); the silt cover varied in thickness from 10 to 30 cm.

**Variability in Site Preservation**

One of the principal results of the Isampur excavation concerns the identification of a regular horizon belonging to the Middle Palaeolithic culture which in India is dated to the Late Pleistocene. The stratigraphy exposed in Trenches 1 and 3 shows that this culture post-dates the Acheulian culture. While in Trench 1 the Middle Palaeolithic was found to directly overlie the Acheulian horizon, in Trench 3 a sterile brown silt layer was found to occur between the

Table 1: Stratigraphy of Trench 1

| Depth below surface | Sediment/Cultural Feature |
|---|---|
| 0-10/20 cm | Black sticky clay of recent fluvial origin |
| 20/25-30 cm | Colluvial gravel lens in a matrix of brown silt and made up of angular to sub-angular pieces of Intertrappean chert; some Middle Palaeolithic artefacts |
| 30-40 cm | Upper portion of the Acheulian level consisting of fresh artefacts, limestone pieces and blocks set in a hard matrix of kankary brown silt |
| 40-50 cm | Lower portion of Acheulian level, overlying limestone and exposed as two digging levels (45 cm and 50 cm below surface). In the 1999 season the 45 cm level was fully exposed and recorded. The 50 cm level will be exposed in the next field season. |

Table 2: Stratigraphy of Trench 2

| Depth below surface | Sediment/Cultural Feature |
|---|---|
| 0-10/15 cm | Black sticky clayey sediment of recent fluvial origin |
| 10/15-20 cm | Horizon consisting of redeposited Acheulian material and limestone blocks derived from the scouring of the up-stream parts of the site |
| 15/20-30 cm | Undisturbed Acheulian material (exposed in an area of 3 m² only) in a matrix of brown calcareous silt similar to that found in Trench 1. |

Table 3: Stratigraphy of Trench 3

| Depth below surface | Sediment/Cultural Feature |
|---|---|
| 0-20 cm | Sterile compact black silt without any cultural material |
| 21-30 cm | Black silt containing Intertrappean chert nodules and a few flake artefacts of the Middle Palaeolithic culture |
| 31-35/40 cm | Sterile brownish silt |
| 36/41-55 cm | Acheulian cultural material in a matrix of hard brown calcareous silt directly overlying limestone bedrock. It was excavated and recorded as two levels (45 cm and 55 cm below surface) |

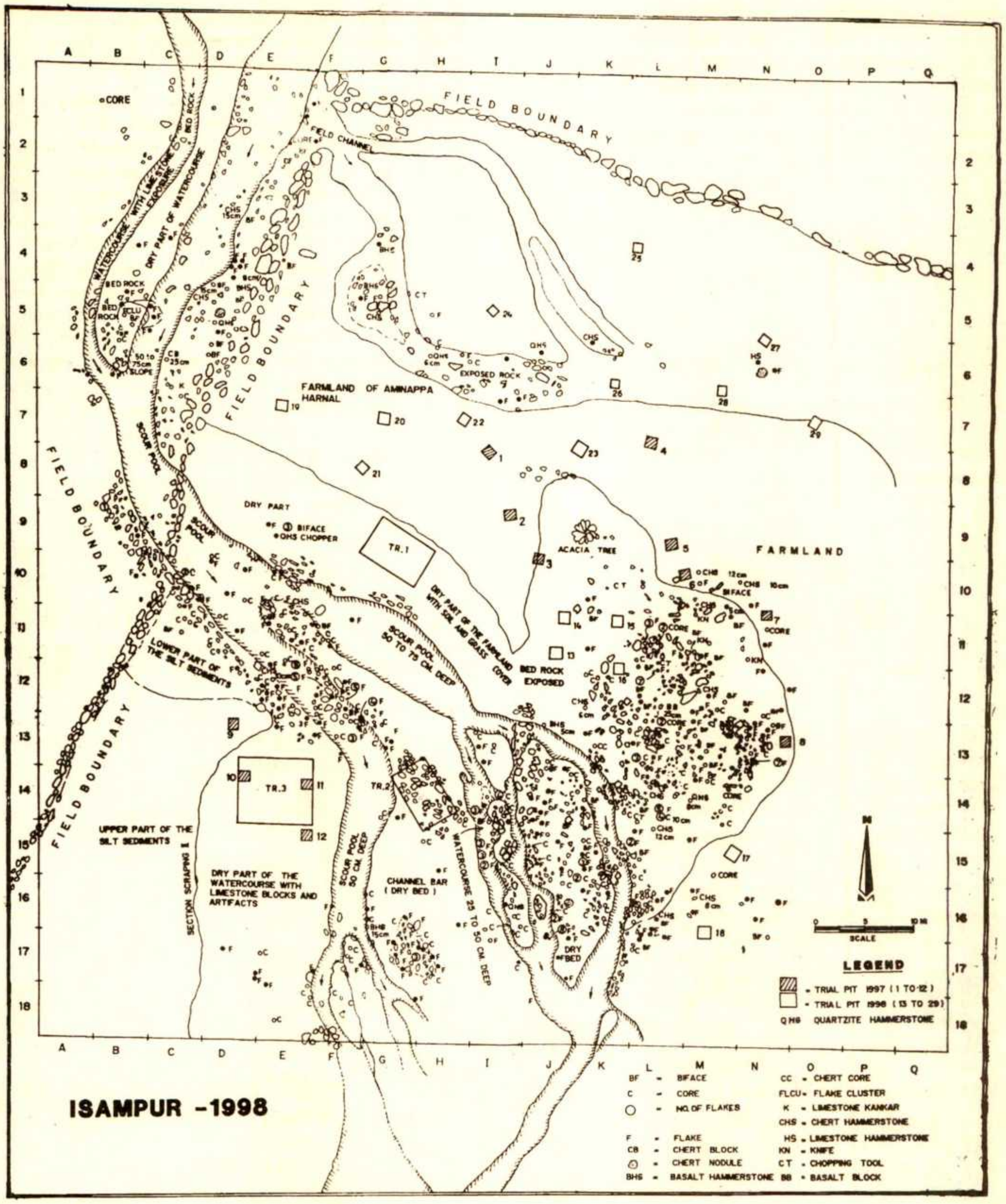

**Fig. 3**: Map of Isampur Acheulian locality showing grid-wise distribution of limestone blocks and Acheulian artefacts found on the surface, and the location of test-pits and excavated trenches

Acheulian horizon and the Middle Palaeolithic tool-bearing horizon. Even though in Trench 3 the Middle Palaeolithic horizon occurred in a disturbed black silt matrix, the presence of the sterile brown silt between the Acheulian and Middle Palaeolithic levels clearly emphasises that the latter culture, stratigraphically speaking, belongs to the upper part of the brown silt. The colluvial gravels within the silts, consisting of subangular to angular cherts and quartzite cobbles, were utilised for the manufacture of artefacts. The presence of cores as well as debitage and their fresh physical condition prove that chipping took place locally. Some of the artefacts do show traces of smoothing which suggests that they were either exposed to weathering processes or underwent short distance transportation on the valley floor. But this observation does not affect the overall primary character of the assemblage.

The second and more important contribution made by this excavation concerns the identification of signatures of differential preservation of the Acheulian level. Our inspection of the sedimentary contexts, physical condition and spatial arrangements of the cultural material and associated clasts made it possible to infer the existence of clear-cut variability in preservation within the site. This variability ranges from intrasite fluvially displaced situations (as in Trench 2) through primary contexts that are partially modified due to the interplay of past erosional and depositional processes as well as contemporary land modification activities (as in Trench 3) to a primary context which shows a high level of integrity and even point provenance of artefacts (as in Trench 1). These observations merit some elaboration.

In Trench 2 the original black/brown silt overlying the Acheulian level has been completely removed due to quarrying and erosion. The rubble gravel found below the 10 to 15 cm thick black sticky clay of recent origin consisted of limestone artefacts and blocks, and pieces of Intertrappean chert and calcrete (Fig. 4). Their loose condition resulting from loss of matrix and edge-wise or slanting/overlapping spatial positions in many cases are a clear proof that this deposit is secondarily derived from the northern elevated part of the watercourse. This intrasite displacement took place subsequent to quarrying of sediments in recent times. The watercourse itself which previously had the form of a broad sheetflow, was made to assume a regular channel form by the preparation of field bunds. This channelised watercourse not only led to the removal of silt cover but even caused bedrock scouring and localised displacement of the Acheulian cultural material. The cultural material of the rubble horizon, while still retaining the attribute of spot provenance and as such being useful for studying hominid technological and typological features, has lost its original integrity; the individual pieces no longer fulfill the criterion of point provenance. (The concepts of site provenance and point provenance had been introduced earlier by the senior author (Paddayya and Petraglia 1995: 345-6) while studying the formation

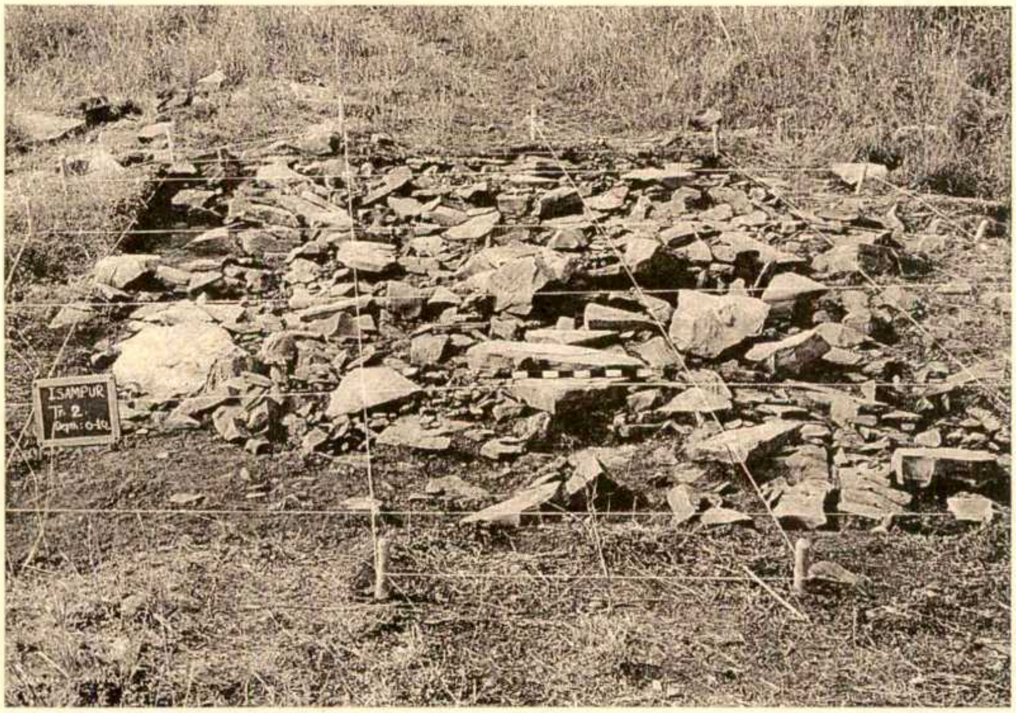

**Fig. 4**: Trench 2 showing fluvially rearranged Acheulian cultural material below 10 cm thick fluvially deposited black sticky clay

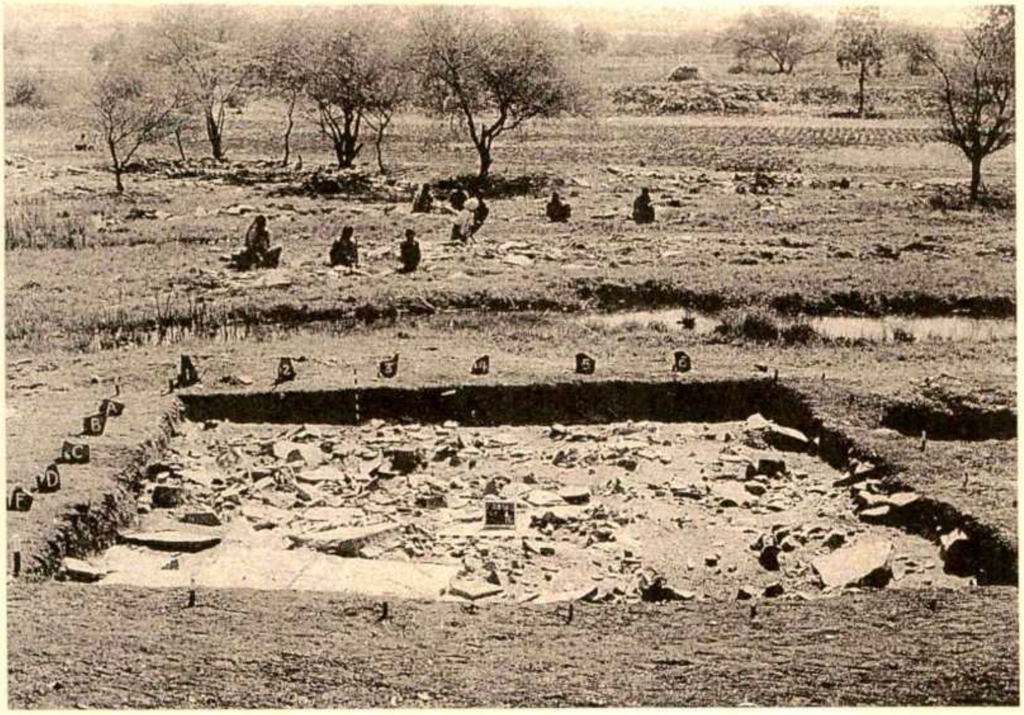

**Fig. 5**: Trench 3 (facing west) showing quarried patches in an otherwise undisturbed Acheulian horizon excavated at 55 cm level below surface. Note the area immediately to the east strewn with limestone blocks and Acheulian artefacts

processes of the Acheulian sites of Hunsgi and Baichbal valleys.)

In a 3 $m^2$ area of the trench excavation was continued further down. Below the rubble gravel the Acheulian horizon was found in an undisturbed context at a depth of 15/20 to 30 cm below surface. A large number of flakes, debitage, cores and shaped tools with sharp facets were found to occur on their flat surfaces on the limestone pediment. These artefacts were embedded in a carbonate-rich brown clayey silt matrix similar to that found associated with the Acheulian level in Trenches 3 and 1.

Trench 3 produced evidence of two kinds of preservational contexts: a) *in situ* context of the cultural material and b) its modification due to post-depositional processes of more recent times. As mentioned before, quarrying of silt in this area left behind irregular pit-like depressions of various sizes, some of which cut through the Acheulian level (Figs. 5 and 6). Subsequently these were filled up with black silt of variable thickness (10 to 30 cm), derived by the combined action of gravity movement from the upper slopes and fluvial activity of the watercourse. In this process some isolated limestone blocks and stone tools, which were probably scooped out from the Acheulian level during quarrying but left out after sediment transportation, were incorporated into the sediment. Chert nodules and flake tools of the Middle Palaeolithic tradition, which probably occurred in the upper part of the brown silts, are now found in a shuffled up condition at the bottom part of the reworked black silt.

In the Acheulian level there are some narrow patches filled with black soil and these present a sharp contrast to the intact Acheulian level lying within a matrix of hard, carbonate nodule-rich brown silt. These soil patches represent the depressions resulting from soil quarrying, action of rills forming part of the watercourse and channel-making activity of the farmers to divert water from the watercourse to the adjoining farmland. This channel-making activity also resulted in the creation of narrow ridge-like features consisting of artefacts and stone blocks dug up from the channels and used to raise banks along them.

The above-mentioned disturbances notwithstanding, the Acheulian level is preserved in a primary context in those parts of Trench 3 which were left untouched by quarrying and channel-making activities. This is attested to by the unabraded condition of artefacts and their flat spatial positions as well as by the hard calcareous brown silt matrix of the horizon.

The sedimentary and spatial contexts of artefacts making up the Acheulian horizon exposed in Trench 1 clearly show that this portion of the site was least affected

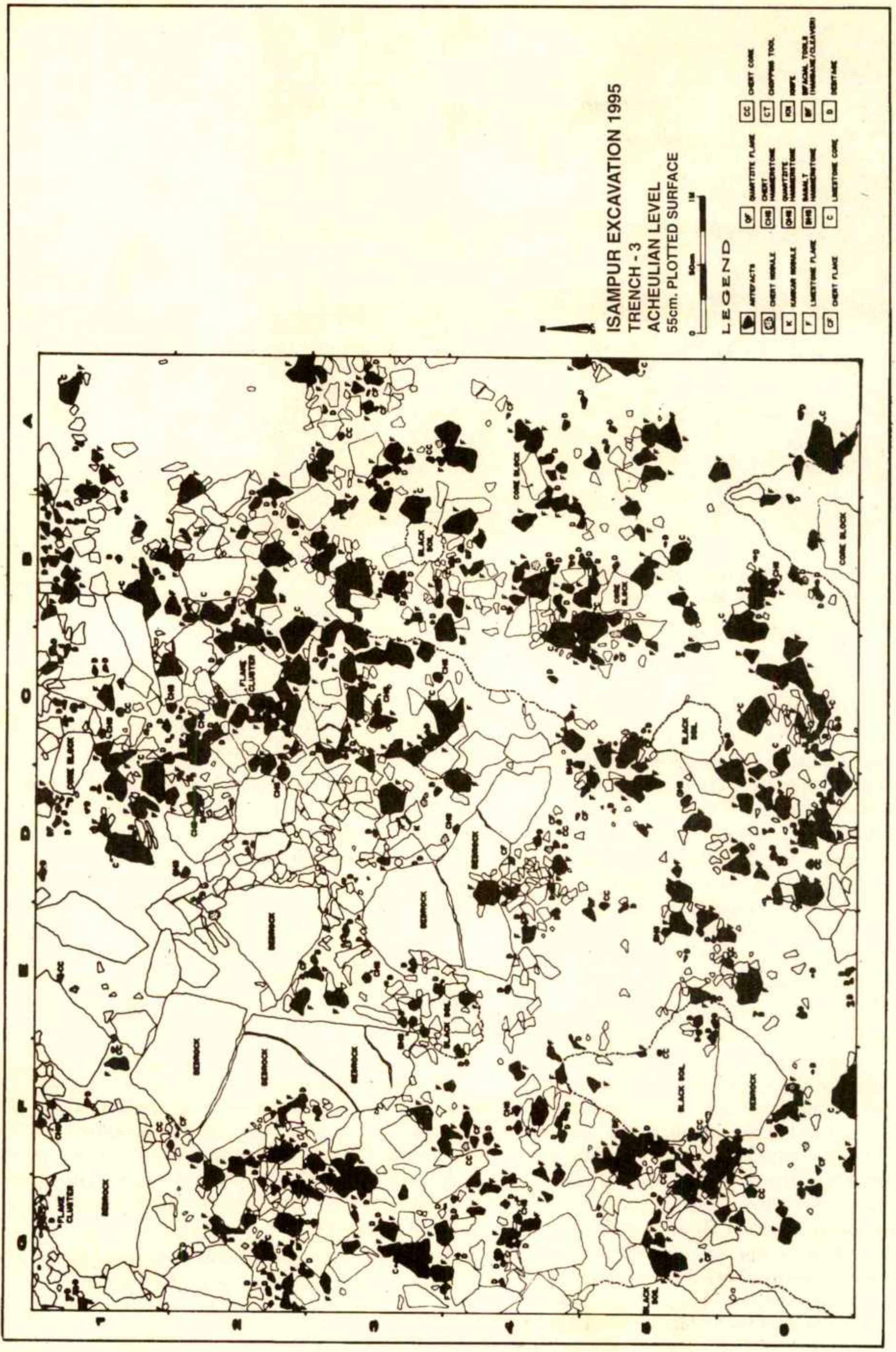

**Fig. 6**: Trench 3 showing undisturbed spatial positions of limestone blocks and Acheulian artefacts exposed at 55 cm level below surface, interspersed with blank patches indicating disturbance caused due to soil quarrying in recent times

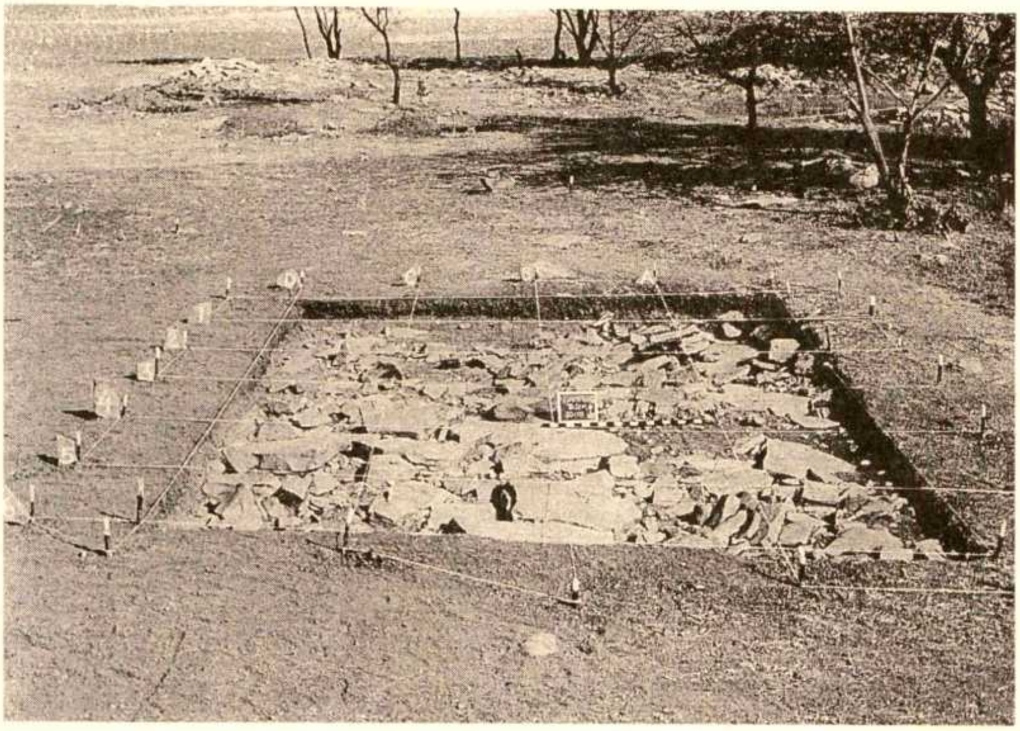

**Fig. 7**: Trench 1 (facing northwest) showing the Acheulian horizon in primary context as exposed at 40 cm below surface. Note the large limestone blocks forming part of the pediment surface

by recent land modification activities and ancient post-depositional processes (Figs. 7 and 8). In fact, one is fully justified here in using the label primary context, with most of the artefacts and stone blocks even fulfilling the criterion of point provenance. Artificial clustering and spatial jumbling of pieces noticed in Trenches 2 and 3 are absent here. The flat positions and fresh and unmodified surfaces of artefacts and other clasts, their embedding in a matrix of hard carbonate nodule rich brown silt, and the occurrence of debitage pieces even smaller than a centimetre in size afford a good opportunity to reconstruct hominid behaviour with special reference to raw material utilization and lithic reduction sequences.

Considering the very fresh condition of the Acheulian artefacts, the vast majority of which are made on limestone, as well as the presence of a large amount of debitage consisting of small pieces, it would appear that the artefacts did not remain exposed to the surface for a long period. Probably at the time of hominid occupation the limestone surface had some silt cover into which the artefacts including the small-sized debitage were incorporated. This silt cover, together with other factors like ground vegetation and the presence of many disjointed limestone blocks, protected the assemblage from spatial displacement by surface runoff which operated in the past on the valley floor. The Acheulian horizon is a palimpsest preserving the record of a series of episodes of site use. Subsequently it was covered with black/brown silts derived from the uplands. This silt cover probably involved a series of depositional episodes interrupted by minor deflational/erosional episodes and accumulation of colluvial gravels. The Middle Palaeolithic groups used chert nodules from these gravels for chipping their flake tools.

### Hominid Behavioural Patterns

Detailed metrical and typo-technological studies of the lithic material obtained from the excavation are under way and hence only a few general observations can be made here to highlight the basic character of the Isampur Stone Age site. The two main aspects of the site brought into focus by the work done so far are, a) identification of a Middle Palaeolithic level, and b) availability of additional evidence reinforcing the view that the Acheulian level at Isampur represents an extensive quarry-cum-workshop associated with a weathered natural bedrock of limestone forming part of the valley floor. The site therefore occupies a unique place among the Acheulian sites of the Hunsgi and Baichbal valleys in particular and of the country in general. MNK chert factory site, dated to the lower part of Bed II at Olduvai Gorge, is a well-known example of this site category in the Lower Palaeolithic studies (Stiles 1998).

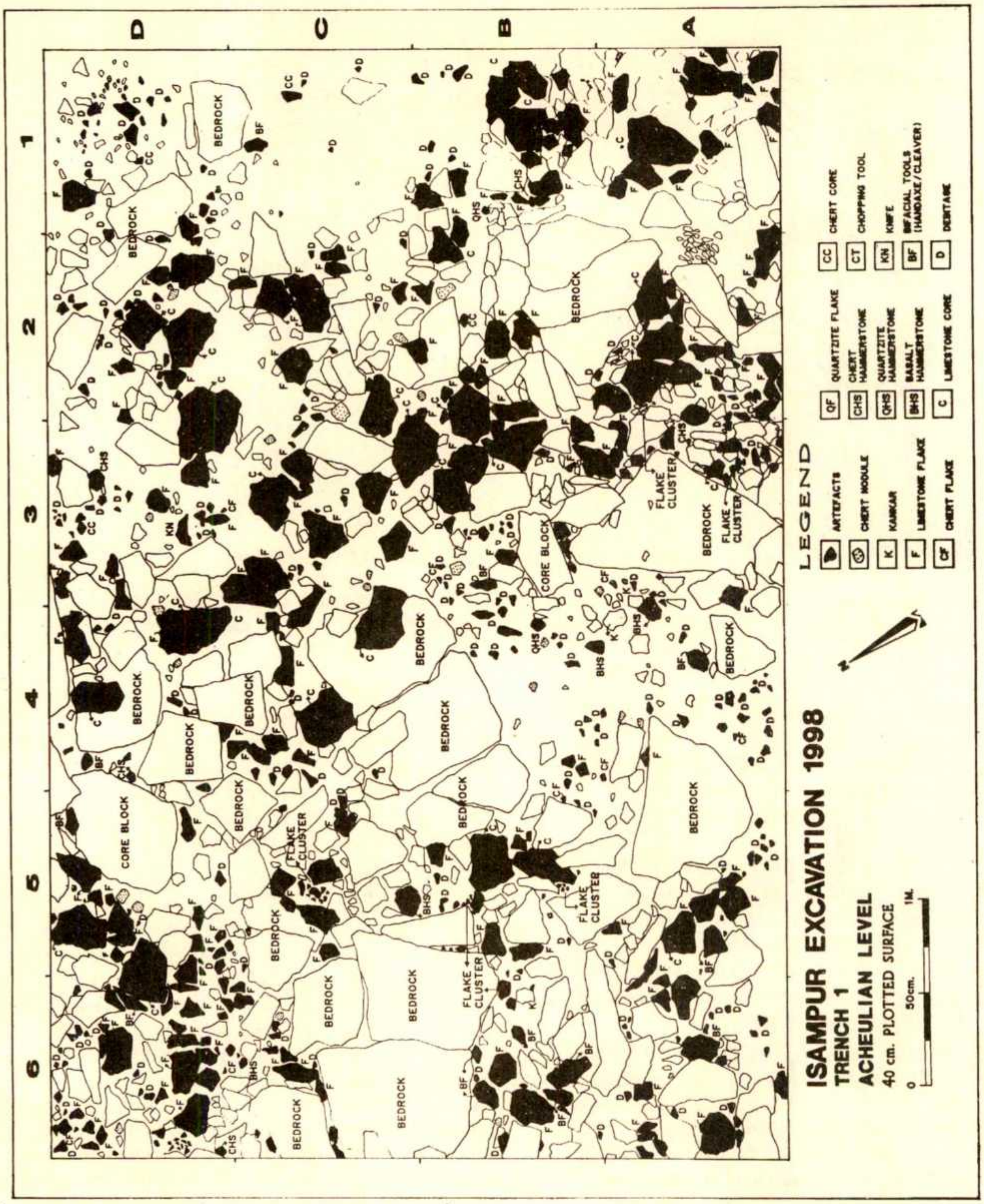

**Fig. 8**: Trench 1 showing spatial positions of limestone blocks and Acheulian artefacts in primary context, as exposed at 40 cm below surface

## Middle Palaeolithic Tradition

Isampur is an addition to the large number of Middle Palaeolithic sites in the Shorapur Doab, brought to light by the first author over the last quarter-century (Paddayya 1974,1987a). These are surface sites found mainly on the slopes and flat tops of the uplands flanking the Hunsgi and Baichbal valleys including the Isampur Valley. The cultural material consists of flake tool assemblages, based on the working of chert nodules derived from Intertrappean chert beds and limestone formations. A limited number of

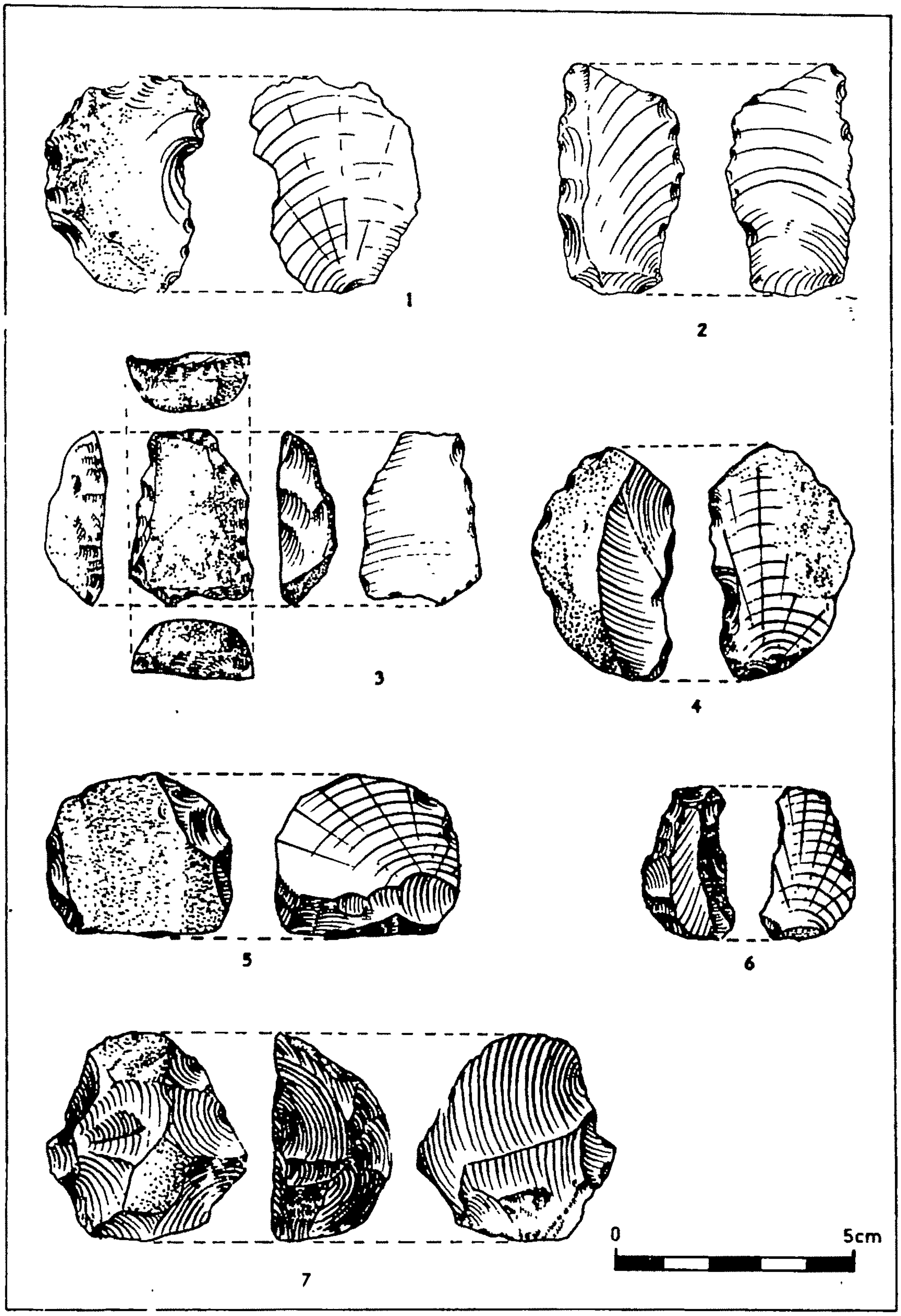

**Fig. 9**: Middle Palaeolithic artefacts of chert from colluvial gravel lens overlying the Acheulian level exposed in Trench 1 at Isampur: 1-6, scrapers of various types on flakes; 7, core scraper

artefacts are made on quartzite derived from pre-Trappean pebble beds exposed on the plateau separating the Hunsgi and Baichbal valleys.

The Middle Palaeolithic assemblage from the Isampur excavation compares well with these assemblages both with respect to raw material and typo-technological features. The assemblage from Trench 1 (15 cm plotted level) consists of about 220 specimens which include finished tools (25), cores (8), hammerstones (4), flakes and debitage. Apart from chert and quartzite there is also the use of limestone in some cases. Two flaking techniques were adopted to remove primary blanks. One is the simple flaking technique aimed at the production of flakes retaining full or partial cortex on their dorsal surfaces. The second technique consists of detaching flakes from prepared cores. Such flakes tend to have fully worked dorsal surfaces and regular shapes.

Flakes obtained by these techniques were transformed into regular tools by the application of margin retouch or, in some cases, steep flaking. Scrapers constitute the largest number of regular shaped tools, with side, end, straight-edged, concave-edged, round, notched and core scrapers forming the major sub- types (Fig. 9). Other types like points and borers are also represented but in a limited number in the assemblage.

### Acheulian Tradition

The Acheulian level exposed in Trenches 1 and 3 measured about 20 cm in thickness. As a matter of convenience, the deposit was exposed as two successive horizontal units during the actual process of excavation — levels 30 to 40 cm and 40 to 50 cm below surface in Trench 1 and levels 35 to 45 cm and 45 to 55 cm below surface in Trench 3. All artefacts and stone blocks exposed in these designated levels were plotted and a full record was kept of their spatial contexts. Trench 1 yielded a total of over 570 artefacts. The two levels together from Trench 3 produced over 450 artefacts. In addition a number of artefacts were found in both trenches in the sediment that was excavated for reaching these plotted levels.

The assemblages from the two trenches, taken together with the surface collections from the site, constitute reliable evidence both for understanding the overall character of the Isampur site and for reconstructing the hominid technological organization system or *chaîn opératoire*. As defined by Sellet (1993: 108), "The *chaîne opératoire* aims to describe and understand all cultural transformations that a specific raw material had to go through. It is a chronological segmentation of the actions, and mental processes required in the manufacture of an artefact and in its maintenance into the technical system of a prehistoric group. The initial stage of the chain is raw material procurement and the final stage is the discard of the artefact".

Three features of the Isampur Acheulian assemblage are very striking. One of these concerns the large spatial extent of the site and unusually rich nature of the cultural assemblage consisting easily of several thousand specimens. It is obvious that the site was used for a prolonged period. As inferred earlier, the exposed Acheulian level is a palimpsest of a series of episodes of hominid use of the spot. The prolonged occupation of the site was primarily due to the easy and on-the-spot availability of raw material in the form of a large number of limestone blocks of ideal shapes and sizes. Secondly, the composition of the assemblage is characterised by the preponderance of cores and debitage and a conspicuously low percentage of finished tools (bifacial ones and others). Thirdly, there is a great variety in the debitage; the products range from rough core dressing flakes to flakes and chips obviously resulting from the final stages in the manufacture of regular implements. Fourthly, a large number of hammerstones of quartzite, chert, basalt and even a crystal-like rock were found both on surface and in the excavation. The latter three features clearly prove that the Isampur site is quite different from almost all the other Acheulian sites in the Hunsgi and Baichbal valleys. It is a true quarry-cum-factory site from where finished tools were transferred to other places in the vicinity for actual use. In fact in 1983 several small Acheulian sites yielding a limited number of regular tools were discovered by the first author on the floor of Isampur Valley. In the course of their foot-surveys of the northern plateau conducted in 1994 and 1997 the authors came across several instances of stray flake tools and fossil fauna. All these valley floor and plateau locations lie within a radius of 6 to 8 km from Isampur. Isampur obviously played the role of a localised manufacturing and supply centre.

Our preliminary studies allow us to infer the major processes involved in the reduction sequence, viz. selection of raw material blanks, core preparation, production of flake blanks and preparation of shaped tools. As described earlier, raw material was easily available on the surface of the site in the form of highly siliceous, 10-15 cm thick limestone blocks of various sizes resulting from weathering of the bedrock. These blocks, on account of the angularities formed at the intersection of flat surfaces and steep sides, served as ideal cores for flaking (for further details about this aspect, see Petraglia *et al.* 1999). The site also preserved evidence of quarrying in the form of prying off of disjointed blocks from bedrock.

The limestone blocks measure up to 30 or 40 cm along the major axis and are of squarish, triangular and rectangular shapes. Using one of the steep sides (i.e. the thickness of blocks) as the platform region, a blow was delivered with a large hammerstone (measuring from 15 to 17 cm across) and this led to the transfer of force to the body of the block and consequent detachment of a fairly large flake. Such flakes generally preserve the cortical surface of parent blocks. In the case of blocks with irregular outlines, the angularities of corners were flaked away in order to bring the block to a suitable shape and also to obtain a suitable platform for flaking. The resultant flakes, called core dressing or preparation flakes, are irregular shaped, cortical flakes of varying sizes. Once flaking was initiated on the blocks, it was continued, sometimes in alternate directions, in order to obtain flake blanks. Cores showing three or four negative flake-scars are quite common. In some cases massive flakes served as cores for detaching further flakes. A large variety of waste products are identified in the assemblage and can be related to various stages of lithic reduction including the preparation of shaped tools. It is proposed to undertake a detailed analysis of this component of the assemblage as well as some experimental studies to understand the processes contributing to assemblage formation (for some examples of similar studies, see Amick and Mauldin 1989).

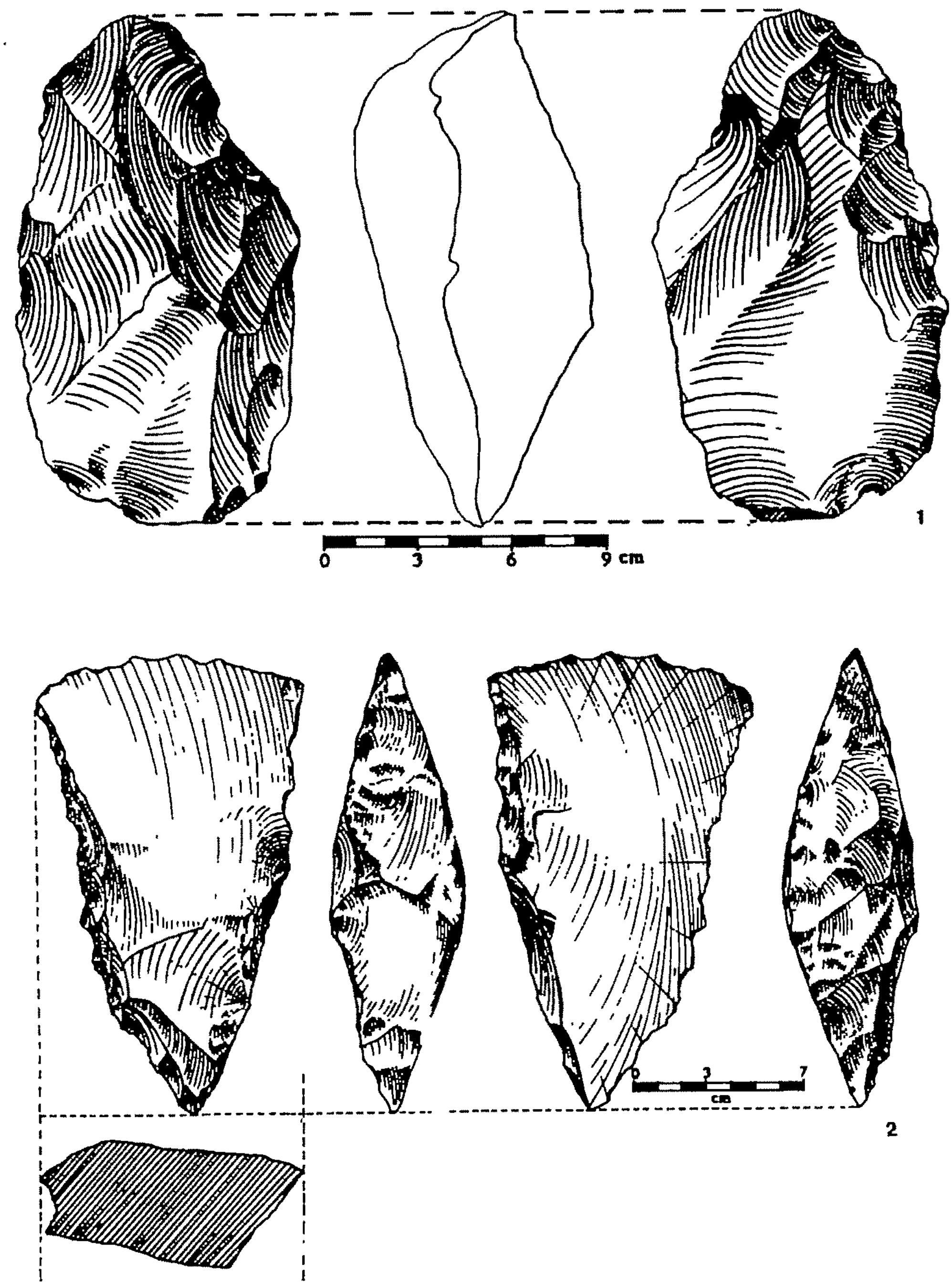

**Fig. 10**: Bifacial tools (1, handaxe and 2, cleaver) manufactured on flakes

The flakes obtained by these methods possess very prominent bulbs of percussion and are massive in size, measuring 15 to 20 cm along the major axis. Their large size is a function of both the relatively soft nature of the raw material itself and the scope for ready initiation of the flaking process, as facilitated by the presence of angularities on the limestone blocks. Flakes with squarish, rectangular or triangular outlines and suitable sizes needed little or no further shaping. The thick and steep bulbar-end formed the butt, while the sharp edge at the opposite extremity, resulting from the intersection of the sloping dorsal surface and the flat ventral surface of the flake, served as the working end. Such flakes could have served as ideal chopping tools and knives.

The thin and slender series of flake banks were subjected to elaborate margin and/or surface chipping to produce bifacial tools (handaxes and cleavers) (Fig. 10). Smaller hammerstones (8 to 9 cm across) were used for this purpose. This process of secondary reduction is amply borne out by the occurrence of a large quantity of well-shaped and thin debitage flakes (easily mistaken for Levallois flakes) showing flake scars on their dorsal surfaces. The Isampur hominids also adopted a second mode of manufacturing bifacial tools, i.e. the use of thin, complete limestone blocks themselves and subjecting them to margin and surface working. The by-products of this process are similar to those resulting from the reduction of flakes into bifacial tools. Departing from the existing interpretations of variability in biface morphology and size in terms of space-time systematics, McPherron (1994) has recently put forward a processual explanation linking variability to the lithic reduction sequence.

Chopping tools, knives, handaxes, cleavers and scrapers are the main tool-types of the Isampur assemblage. From the massive sizes of artefacts and their thick cross-sections and pointed shapes of bifaces, it is easy to infer that we are dealing with an Early Acheulian assemblage. In this connection it may be recalled that the lower time limit of the Acheulian culture of the Hunsgi and Baichbal valleys stretches beyond 3,00,000 years (Szabo *et al.* 1990; Paddayya 1991). It is claimed that sites like Bori, also located in peninsular India, are 6,00,000 to 7,00,000 years old (Mishra 1992; Mishra *et al.* 1995).

The Acheulian level in Trench 1 yielded a small amount of fossil fauna comprising dental and bone pieces of wild cattle (*Bos* sp.), limb bone fragments of some unidentified medium-sized mammals and shell fragments of the pond turtle (Genus *Clemmys*). This evidence, slender though it is, is helpful in reconstructing past environments and hominid food habits.

In conclusion we would like to emphasise that the Acheulian site near Isampur has not only provided valuable evidence for addressing the challenging methodological problem of the investigation of natural and cultural formation processes of the Stone Age archaeological record but has also given new insights into hominid cognition relating to landscape understanding and use, and the organisation of technological and settlement systems. We plan to undertake further field research at the site in order to place the observations made in the present article on a sounder footing.

## Postscript

Another season of fieldwork was undertaken at the site during February and March 1999 which mainly concerned excavation. Trench 1 was enlarged to cover a total area of 60 m$^2$ and, close to it, two additional trenches (Trench 4 measuring 12 m$^2$ and Trench 5 measuring 9 m$^2$) were excavated. The evidence from these trenches places beyond doubt our earlier inferences about the hominid identification and selection, for purposes of working, of a limestone outcrop consisting of thick slabs of suitable sizes and shapes. (It is proposed to use this and further data that may be acquired, for making a geological map, reconstructing the original limestone outcrop as it was first encountered by the hominids.) These trenches also confirmed the primary character of the Acheulian level in this part of the site and the existence of a Middle Palaeolithic level associated with colluvial gravel within the brown silt overlying the Acheulian level. As a part of this season's work explorations including a contour survey were carried out in the surrounding area. These field studies confirmed the existence of a palaeodrainage tract adjoining the Stone Age site. Four cuttings were excavated to understand the thickness and character of the sediments filling up this ancient drainage tract. In three of these cuttings a small number of Acheulian artefacts were found on the eroded surface of the limestone, thereby establishing the pre-Acheulian age of the drainage tract. The eroded limestone surface of the drainage tract was overlain by brown calcareous silt (1.20 m thick), which was in turn capped by black silt (1 m thick). In one of the cuttings (cutting I) the two deposits were separated from each other by a disconformity clearly showing that these deposits are distinct sedimentary bodies (Fig. 11). Further, each deposit showed evidence of internal stratification, which obviously implies that several depositional episodes were involved in their formation. Finally, in two of the cuttings Middle Palaeolithic artefacts were found in the upper part of the brown silt.

## Acknowledgements

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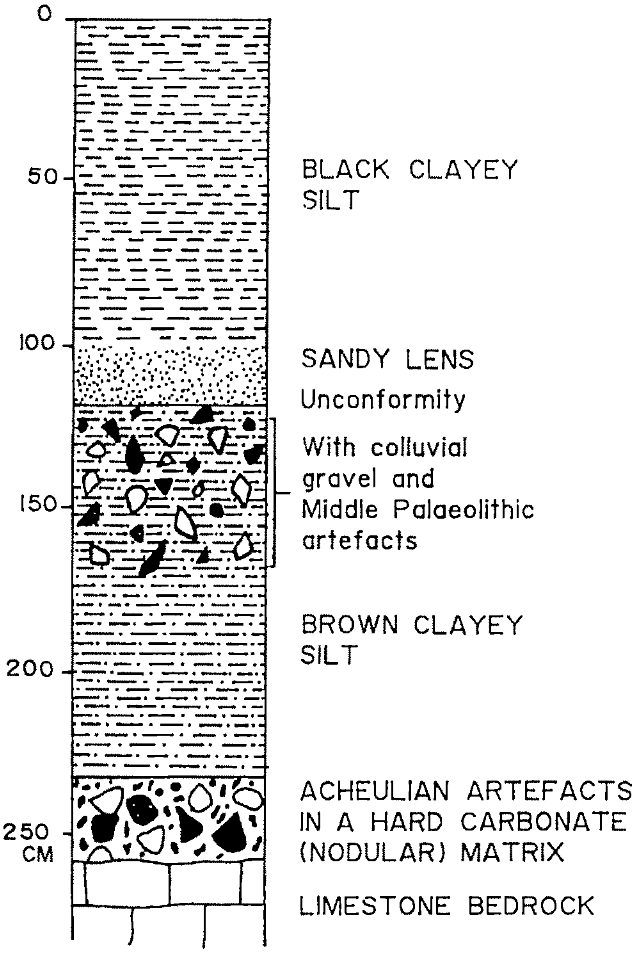
0
50
100
150
200
250 CM
BLACK CLAYEY SILT
SANDY LENS
Unconformity
With colluvial gravel and Middle Palaeolithic artefacts
BROWN CLAYEY SILT
ACHEULIAN ARTEFACTS IN A HARD CARBONATE (NODULAR) MATRIX
LIMESTONE BEDROCK

**Fig. 11**: Stratigraphy exposed in Cutting I (excavated in the palaeodrainage tract) showing black and brown silts and the relative stratigraphical positions of the Acheulian and Middle Palaeolithic horizons

and Shri Aminappa Harnal (owner of the land where the Stone Age site was excavated). A number of M.A., M.Phil. and Ph.D. students of the Department of Archaeology, Deccan College, Pune participated in the excavation. Shri Bilal R. Khrisat provided excellent support by regularly participating in the excavations conducted in 1997, 1998 and 1999. The technical staff of the Institute participated in the fieldwork and prepared contour survey and site maps, and plottings of excavated cultural levels. They included D.D. Phule, B.S. Waghmode, S.D. Rokade, D.V. Karanjkar, S.A. Pradhan, B. Dighe and V.G. Vishwasrao. Shri Sunil Jadhav and Shri Ravi Dhamapurkar attended to the photography work. Shri Ashok Omble, Shri Chandrakant Shendge and Shri H.S. Balakrishna managed the excavation camp. Finally we are grateful to Dr. G.L. Badam for his preliminary identification of the fossil fauna from Isampur.

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# The Sub-Andean Loess of Northwest Argentina: a Concise Review

Edward Derbyshire

Centre for Quaternary Research
Department of Geography, Royal Holloway
University of London, Egham
Surrey TW20 0EX
U.K.

## Introduction

Although there is a very broad range of opinion on the definition of the term 'loess' (for reviews see, for example, Pye 1987, 1995), an aeolian source for the constituent particles of loess is widely accepted. Aeolian dust is capable of affecting the earth's climate by way of its effect upon the radiation balance (e.g. Li *et al.* 1996) and, when it occurs as a thick sedimentary formation, it also provides a detailed record of varying continental aridity and past changes in the global circulation of the atmosphere.

Increasing attention is being given to the dust record found in deep-sea sedimentary accumulations and in cores taken from ice sheets and glaciers. Accumulation rates and median grain size of lithogenic particles in oceanic cores have been used to assess the extent of changes in continental aridity and as a mean wind speed proxy, respectively (e.g. Rea 1994; Rea and Leinen 1998; Ruddiman 1997). Dust in ice cores from both Antarctica and Greenland suggests that dust accumulation rates during the Pleistocene glacials were between 2 and 20 times those typical of the interglacials (Petit *et al.* 1981, 1990; Rea 1994; Steffensen 1997). That this was a global phenomenon is indicated by the fact that even in some low latitude regions, dust accumulation rates during glacials were up to four times greater than during interglacials (Rea 1994). Such a magnitude of change in the depositional regime at glacial/interglacial transitions is a climate proxy of the first order.

Most sources of atmospheric dust in the present interglacial are located in the tropics or sub-tropics, notably in the extensive drylands of North Africa, the Middle East, and central and eastern Asia, but also including the seasonally moist regions. A sparse vegetation cover and readily erodible soils (Tegen *et al.* 1996) are common in such regions. The important influence of a discontinuous vegetation cover on the terrestrial dust flux has been taken into account in some models of palaeoclimates Very recently, Mahowald *et al.* (1999) used the BIOME3 terrestrial biosphere model of Haxeltine and Prentice (1996) to discriminate likely dust source regions for the present-day and for the Last Glacial Maximum (LGM). This model is driven by present-day values of temperature, precipitation and insolation. These are combined with monthly mean climatic anomalies for the LGM (ECHAM3 simulations: Lorenz *et al.* 1996) and carbon dioxide values, 200 ppm being selected for the LGM. The results broadly conform to expectations based on current theory. The model for present-day conditions shows strong dust deposition in the North Africa-Middle East-central and east Asia zone, although the dust transport in the lee of the latter region appears to be underestimated, pointing to an underestimation of this region as a dust source. The simulations for the LGM, incorporating both the change of climate and an expansion of the dust source regions, broadly match enhanced accumulation in the polar ice caps with the major enlarged sources, although input to Antarctica from Australasia appears overestimated in comparison with South America for both the present and LGM conditions, to judge from current geochemical indicators in the Antarctic dust record (Basile *et al.* 1997).

Detailed comparison of model *versus* real data underline the need for greater input of validated sedimentary data from known dust source regions into climatic modelling experiments. Advances in modelling of past periods such as the LGM offer a considerable opportunity to extend the data set to include the terrestrial records, the greatest of which is that provided by the loess-palaeosol successions in central and eastern Asia, and North and South America. The climatic record contained in the loess of South America, and its role as a dust source for Antarctica, has considerable potential for improving understanding of the climate system of the Southern Hemisphere during the Quaternary.

## The Loess of South America

The South American loess is the most extensive in the Southern Hemisphere. Most attention has been accorded to the loess of the Pampa, awareness of the important loess deposits north of 30° S (the sub-tropical loess) having to await the classic paper by Teruggi (1957). Teruggi's map (Fig. 1) is inclusive rather than discriminatory, and includes a diverse suite of loess and loess-like materials. They are believed to be Late Pleistocene and Holocene in age, although there is little basis for the age estimates.

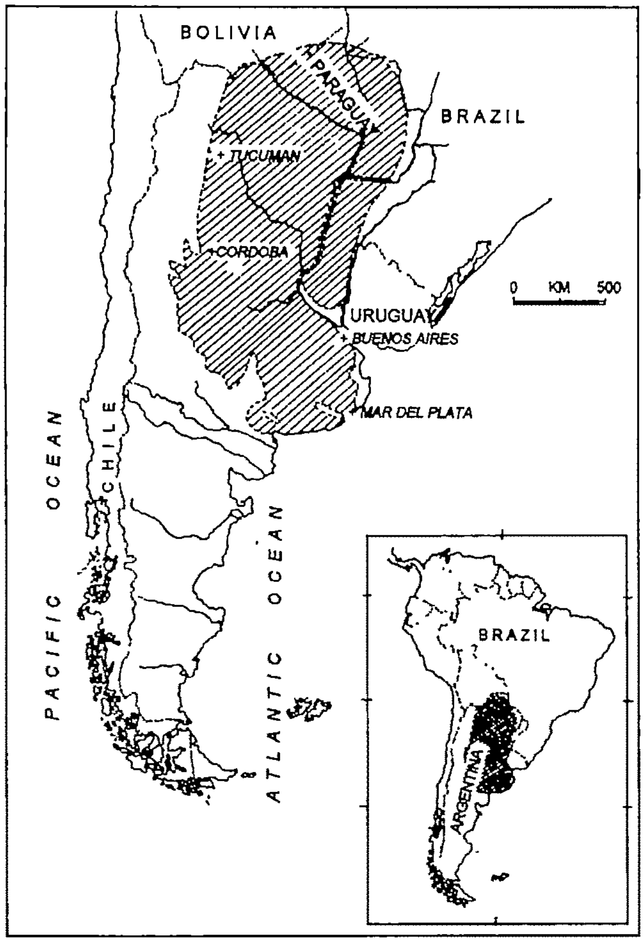

**Fig. 1**: Approximate extent of loessic sediments in Argentina according to Teruggi (1957). Re-drawn from Sayago (1995)

## The Loess of the Pampa

The loess of the Pampa has been regarded as the typical loess facies of South America, since being described by d'Orbigny (1842) and Darwin (1846). In fact, it appears as the only South American loess on several published world maps of loess.

The Pampean aeolian sedimentary system involves a complex of sands and rather sandy loesses situated between about 40 and 30° S. It is distinctly coarser in grain size than the classic Eurasian loesses, being relatively rich in the fine sand grade. It is also somewhat deficient in quartz and $CaCO_3$, and has a higher content of feldspars and volcanic glass than most other loesses. There is also abundant evidence of interstratification of Pampean loess and fluvial facies. Fluvial re-working of loessic sediments may cause complex sedimentary relationships at the local level.

Several models have been proposed to explain the genesis of the Pampean loess, and a number of different sources of the material are assumed. The best known model favours a south-westerly source (Iriondo 1990; Zarate and Blasi 1993): a dominantly south-westerly wind system imposed SW-NE lineaments on a sand sea derived from the reworking of glaciofluvial deposits on the northern Patagonian foreland, with the sediments fining to leeward as in the classic 'glacial loess' model of Western Europe (cf. Smalley 1995). This system integrated a number of glaciofluvial sources from the central Andes in the north to Northern Patagonia in the south. Ash falls also contributed to these accumulations from west and north-west, but it is inferred that the dominant LGM winds came from the south-west (Fig. 2).

## The Sub-tropical Loess

The loess found north of Buenos Aires Province has received much less attention in the literature but poses a

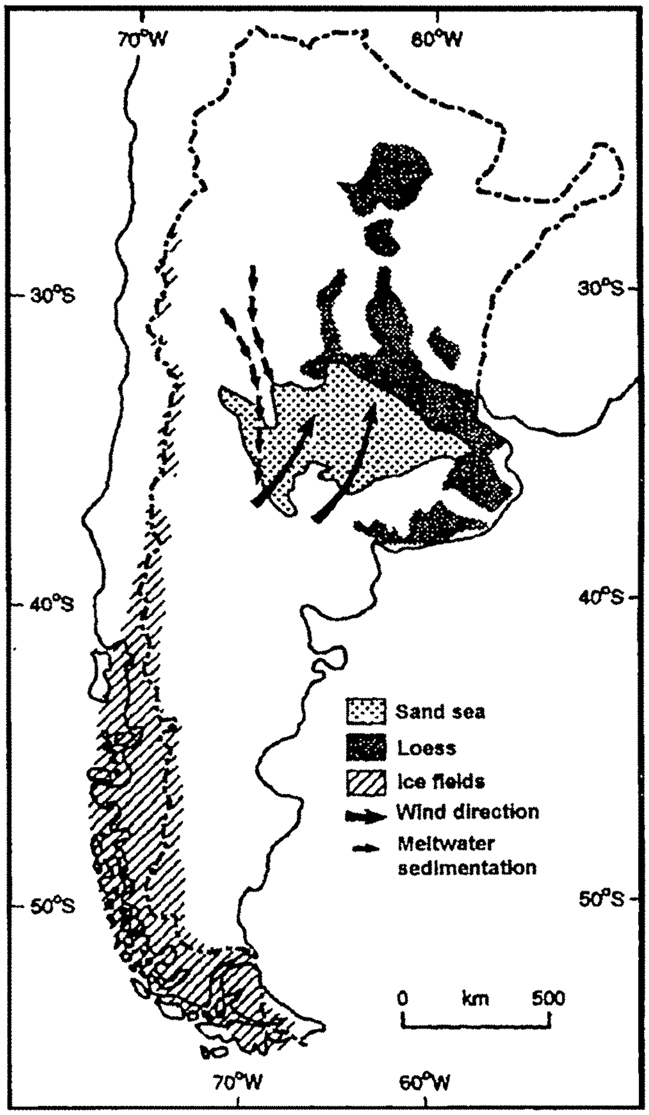

**Fig. 2**: The Quaternary aeolian system according to Iriondo (1990)

number of problems related to sources, palaeo-wind circulation patterns, and degree of reworking.

The sub-tropical (or 'neotropical': Sayago 1995) loess lies between 30 and 20° S, from the Chaco Plain in the east to the sub-Andean mountains in the west. It is distinctly finer than the Pampean loess, with less feldspar. There appears to be a progressive decline in mean particle size northwards from the Pampa into the Chaco Plain. The decline in the sand fraction and complementary rise in the silt percentage has been used to endorse the view that this loess was derived from northern Patagonia and the central Andes, both concentrated and modified by fluvial transportation (Zarate and Blasi 1988; Rabassa 1990), and an exposed continental shelf (Tricart 1975). The driving forces included an extensive ice cover over the more southerly parts of the Andes and a more northerly Polar Front with a diminished subtropical Pacific Anticyclone, yielding a dominantly south to south-easterly wind regime during the LGM, driven by the northerly-displaced sub-polar low pressure track.

An alternative view of the derivation of the sub-tropical loesses explains them in terms of stronger winds from the north in the LGM. Iriondo (1997) argues that dry winter conditions became much longer in the western Chaco with a significant decrease in precipitation in the sub-Andean ranges. Fields of parabolic sand dunes with a clear northerly provenance developed on the plains of Bolivia and Paraguay at the same time as loess in the sub-Andean basins. This system was driven by a persistent anticyclonic circulation in subtropical latitudes (34-24° S) (Fig. 3).

Thus it appears that there remain some uncertainties about the sources of the subtropical loess of north-west Argentina. The northward decrease in mean grain size of the loess on the Pampa and Chaco plains (25-40° S), used to suggest that the source areas lay in extra-Andean Patagonia and the central Andes, leaves aside the fact that there are significant differences in component mineral percentages between the loess of these two regions and that of the sub-Andes.

The sub-Andean loess-palaeosol sequences lie at over 3,000 m amsl, in a dry steppe climate, with mainly summer rainfall and high evaporation. Its thickness increases to the west, reaching more than 40 m in some pre-Andean valleys. Such sites may provide valuable evidence bearing upon the questions outlined above, given more detailed analysis. A site near the small town of Tafi del Valle, about 60 km west of the city of Tucuman, is a case in point.

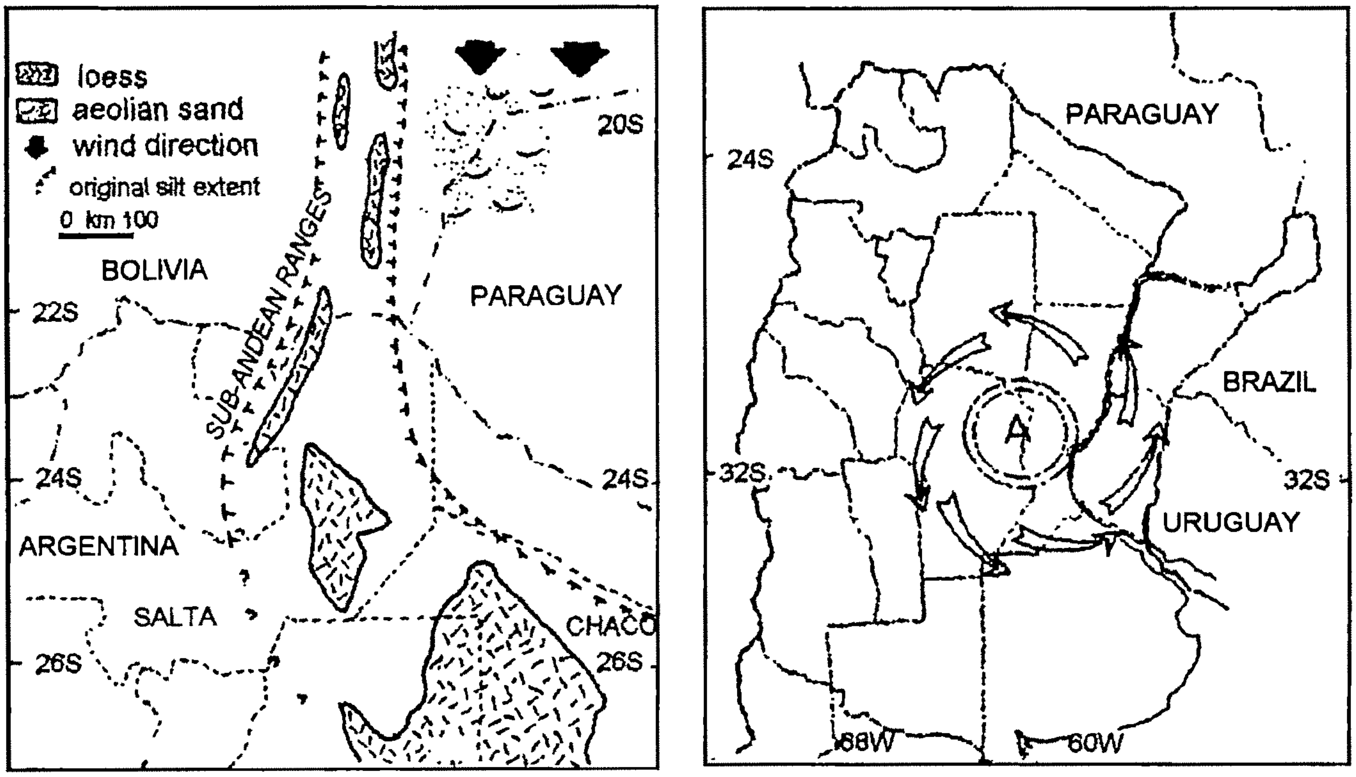

**Fig. 3**: Relationship between dune sand systems and the loess in and north of the Chaco (left) and the dominant circulation pattern responsible for it according to Iriondo (1997)

**Table 1**: Some preliminary magnetic susceptibility values for the upper and lower horizons of the loess-palaeosol section at La Mesada, Tafi del Valle, Tucuman Province, Argentina

| Sample | LF | HF | Xfd(%) | LF-HF | Weight (g) |
|---|---|---|---|---|---|
| **Upper part of section** | | | | | |
| LM 1.70m<br>Loess | 154.96 | 153.75 | 0.78 | 1.21 | 8.26 |
| LM 3.65m (A)<br>Palaeosol | 196.79 | 190.96 | 2.96 | 5.83 | 13.72 |
| LM 3.65m (B)<br>Palaeosol | 196.21 | 190.91 | 2.7 | 5.3 | 13.2 |
| **Lower part of section** | | | | | |
| LM 42.23-42.68m<br>Loess | 130.05 | 128.3 | 1.35 | 1.76 | 11.38 |
| LM 42.68-42.78m<br>'cinerite' | 224.01 | 218.37 | 2.52 | 5.64 | 12.41 |
| LM 43.53-43.83m<br>Palaeosol | 202.45 | 198.85 | 1.78 | 3.6 | 13.88 |

LF = low frequency; HF = high frequency; Xfd(%) = frequency dependency of magnetic susceptibility

## La Mesada: a Sub-Andean Loess Section

The La Mesada section (Sayago 1997; Sayago and Collantes 1991) lies in a sub-Andean basin at an altitude of 2,900 m. This is a dry montane environment, with steppe grassland cover, the 400-500 mm mean annual rainfall occurring mainly in summer. The section is 42.5 m thick. Within it can be observed some 28 layers of a slightly browner colour that have been provisionally interpreted, in the absence of thin section analysis, as palaeosols. Certainly, mean clay content is higher in these layers (23%) than in the intervening loess layers (9%). Moreover, the thickness of the loess units appears to diminish up-profile, with a complementary increase in the thickness and apparent development of the palaeosols (based on clay contents of only 16% near the base rising to 28% near the top of the section). It has been suggested that this increase is a reflection of progressively moister and milder climatic conditions, with more advanced secondary clay generation with height above base. However, preliminary magnetic susceptibility measurements do not show the expected consistent frequency-dependency values (Table 1), so that this hypothesis remains to be rigorously tested.

## Discussion

It is difficult to interpret trends in data such as those currently available for La Mesada. By comparison, a section of loess with 28 palaeosols in North China would indicate that the sequence represented a major proportion of the Quaternary. Much depends on establishing the age of the La Mesada section in a material that contains little that is suited to several current methods of dating. So far, three dates have been obtained using $^{14}C$ on the alkali-abstract fraction of the bulk organic material < 180 µm after removal of roots, etc. The results (Table 2) raise some interesting questions.

Using normal extrapolation, it seems certain that an age of c. 17 kyr at a depth of only 5 m indicates that the upper part of this section has suffered significant erosion, so that the upper part of the record is missing. The date of

**Table 2**: Preliminary radiocarbon ages at four levels within the La Mesada section. Data kindly provided by J.M. Sayago

| Sample Depth Below surface | $^{14}C$ age |
|---|---|
| 5 2m | $17{,}580\pm^{500}_{470}$ |
| 15m | $22{,}000\pm^{420}_{400}$ |
| 27m | $24{,}610\pm^{1230}_{1070}$ |
| 42.3m<br>(base of section) | $27{,}660\pm^{1830}_{1490}$ |

only 27 Kyr for the base of a section over 42 m thick containing 28 palaeosols is even more difficult to explain. If the date is valid, and assuming that the browner layers are of pedogenic origin, this would suggest that a dry-moist oscillation occurred every 500 years. This has a bearing on the question of loess provenance, controlling wind patterns and the cause of moisture influx in soil development. The current view favours derivation of loessic silts mainly from a southerly direction, with moisture derived from the Atlantic. There are other alternatives, including at least partial input of loessic silts from the desertic basins of the Andes to the west, but there is little compelling evidence either way. The present subtropical jet stream crosses the Andes at c. 25° S with an average summer velocity of 20 m/s at a mean Altiplano altitude of 4-6000 m, generating substantial dust transport that is visible on satellite photographs. These westerly air-flows are dry with a strong föhn component that raises dust storms. This raises the question as to the relative roles of the westerly as against the southerly components of the Pleistocene atmospheric circulation in the sub-Andean region of north-west Argentina. Certainly, currently-forming soils in the sub-Andean region are rudimentary, only certain favoured sites showing any evidence of B horizonation.

These and other uncertainties stand in the way of attempts to use the terrestrial loess record in modelling the global dust flux during the LGM. In order to advance this aim a number of requirements stand out, the principal items being as follows.

> Chemical speciation of the sub-Andean loess, the dried lake sediments in the Andes to the west, and the lowland loess to the south using XRF and ICPMS should narrow down the possible sources of the loessic silts.
>
> The use of high-resolution magnetic susceptibility and palaeomagnetic data should provide complementary information on sources, near-surface post-depositional processes, and age.

These and other data are needed to allow comparison of sub-Andean loess successions such as those in the Tafi del Valle basin with the Vostok dust record which should, in turn, yield improved estimates of Southern Hemisphere dust loading to at least 150 kyr B.P.

## Conclusions

Loess deposition in the sub-Andes has been explained in terms of deposition from S.E. winds during the Last Glacial Maximum. A commonly-used model envisages that glaciation in Patagonia and the central Andes generated silts which, after being dispersed across the Andean piedmonts and plains revealed by marine regression, were driven northward by southerly winds, as both the jet stream and the Polar Front were displaced. A northward increase in the content of secondary clays in the Argentine loess and the presence of interbedded palaeosols has also been attributed to a southerly circulation. In other words, both the origin of the (glacial) loess and the generation of the interglacial/interstadial palaeosols have been explained in the same dynamic terms, i.e. driven by a southerly (Atlantic) circulation.

A number of techniques now available promise to throw light on the apparently anomalously youthful age currently accorded to some of the sub-Andean loess, the climatic significance of the buried palaeosols, the provenance of the loess, and the atmospheric circulation that controlled its accumulation. The sub-Andean loess may hold some important keys to improved understanding of the Last Glacial Maximum in the Southern Hemisphere. When used in comparison with the Pampean loess, it should provide a clearer picture of the palaeocirculation of the atmosphere in these latitudes and the relationships between South American loessic dust and the Antarctic dust record.

## Acknowledgements

This review rests heavily upon published and unpublished material on the Argentine loess, and information during numerous discussions at field sites in Argentina, kindly provided over several years by Jose-Manuel Sayago (Universidad Nacional de Tucuman, Argentina). I am also greatly indebted to Sandy Harrison and Karen Kohfeld (Max Planck Institute for Biogeochemistry, Jena, Germany) for the pre-publication copy of Mahowald (1999) discussed in the Introduction, as well as for numerous stimulating discussions of the loess record and its application in modelling the LGM. I should also like to acknowledge Martin Iriondo (CONICET, Parana, Argentina) and Marcello Zarate (UNMDP, Mar del Plata, Argentina) for their field guidance and valuable discussions on a number of occasions over the years. Finally, I thank Dr. Xingmin Meng for the results shown in Table 1.

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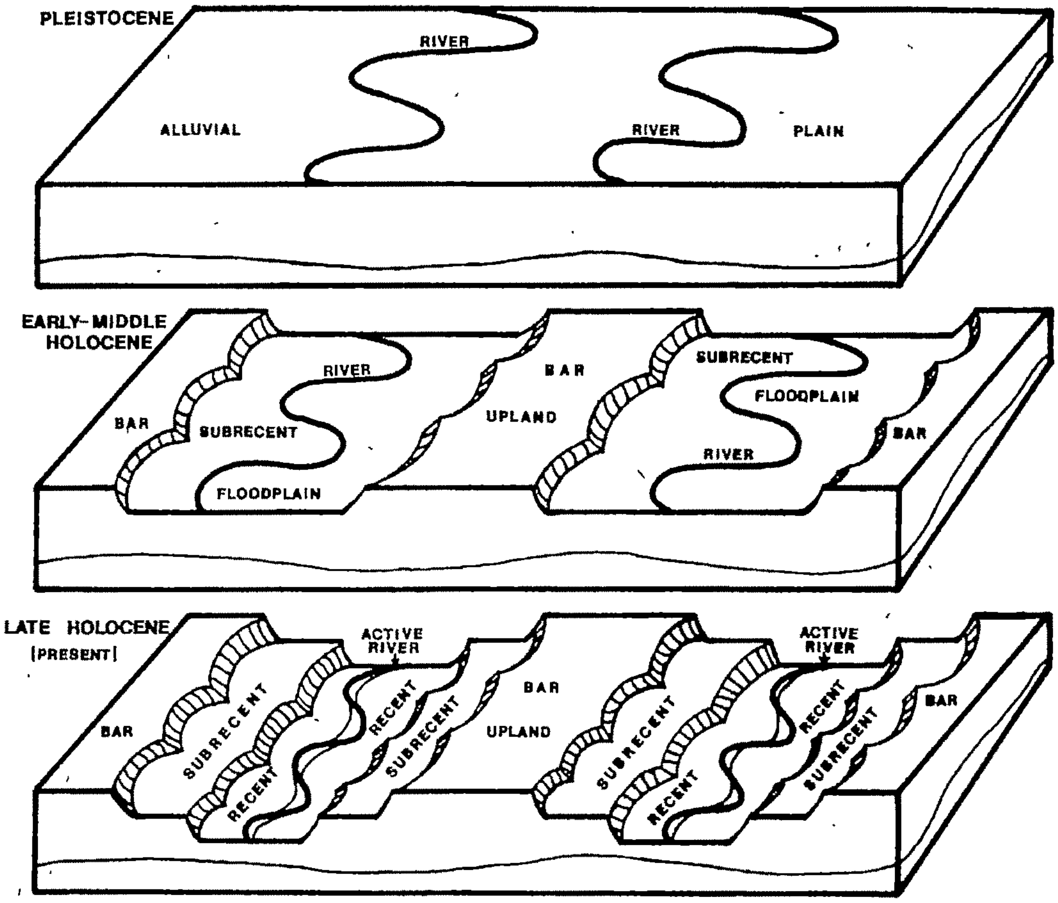

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*Cover*: Development of the Punjab Plains

# Editorial

This issue offers two major articles on the Harappan culture. The first, an exhaustive review by G.L. Possehl, one of the foremost experts in Harappan studies, was earlier published in the Journal of World Prehistory and is reprinted here to provide members of our Society and other Indian scholars an opportunity to have access to it. The second article, a review of some of the former courses of the Indus in Sind by Louis Flam will be of equal interest to our members. The Harappan theme is continued in the paper by P.V. Pathak who finds that the iconography of some of the Indus seals has parallels in the Atharvaveda hymns. R.K. Mohanty documents bead manufacturing at Mahurjhari, a Megalithic site in Vidharba. A note on the newly established Sharma Children's Museum at Chennai is also included. The importance of spreading awareness about archaeology through the educational system is well appreciated and the Sharma Children's Museum is trying to implement this in an innovative way. Book reviews, obituaries, the General Secretary's report and the Society's Audited Statement of Accounts for 1998-99 complete the issue.

After a few delayed issues, *Man and Environment* returns to schedule. With this issue we complete a decade of biannual publication of the Journal during which period Dr. Statira Wadia has been at the helm of the editorial board. She guided the Journal over the important transition from annual to biannual publication, made the editorial process more rigorous, and greatly contributed to a recognition of the Journal as an important archaeological information resource on the national and international scene. After ten years service to the Journal Dr. Wadia will be leaving the editorial board. The editorial committee has very reluctantly agreed to accept her request to be relieved of the editorial responsibilities. We are sure that members of the Society would like to thank her for her hard work and dedication and wish her all the best.

*The publication of this Journal has been financially supported by the Indian Council of Historical Research (ICHR) and Archaeological Survey of India (ASI). The responsibility for the facts stated, opinions expressed, or conclusions reached is entirely that of the contributors of the articles. The ICHR and ASI accept no responsibility for them.*

# The Transformation of the Indus Civilization[1]

Gregory L. Possehl

University of Pennsylvannia Museum,
Department of Archaeology,
University of Pennsylvannia,
Pennsylvannia
USA 19109-6398

## Abstract

Suggested explanations for the "eclipse" of the Indus Civilization (2500-1900 B.C.) are reviewed, along with a description of the culture history that accompanies the abandonment of Mohenjo-daro and many other Mature Harappan settlements. New data are presented from Mohenjo-daro which suggest that the process of change that brought about the eventual abandonment of the site began in the later part of the third millennium B.C. Settlement data from the ancient Sarasvati River, Gujarat, and northwestern India that suggest that there was no general "eclipse" but a process of deurbanization and a shift eastward in the general distribution of the population.

## Introduction

Knowledge of the Indus or Harappan Civilization (Fig. 1) has been enlarged and deepened in recent years and older paradigms for understanding ancient India's earliest civilization (Marshall 1931a-d; Wheeler 1947b, 1953, 1968; Mackay 1948; Piggott 1950) have been abandoned and are being replaced. (Fairservis 1967, 1971; Ratnagar 1991; Possehl 1990, 1996a, 1997, 1998a, b; Kenoyer 1991a, b; Shaffer 1982; Shaffer and Lichtenstein 1989, 1995; Chakrabarti 1995; Jarrige *et al.* 1995; Meadow 1996; Allchin and Allchin 1997; Mughal 1997; Lal 1997). It is widely known that the great metropolitan centre of Mohenjo-daro was abandoned at the beginning of the second millennium. At about the same time Harappa, the urban counterpart of Mohenjo-daro, also underwent a process of change, with a reduction in size and internal complexity. These two observations have led archaeologists to speak of the "collapse" of the Indus Civilization and to seek an explanation for the end of the ancient cities of the Indus. This is the topic addressed in this paper.

Thoughts on the cultural processes leading to the abandonment of Mohenjo-daro, and other changes that Harappan Civilization underwent at the beginning of the second millennium, have paralleled the paradigm changes for the civilization as a whole. The older theoretical positions, and historical reconstructions, have undergone considerable revision over the past two decades. Although there is no clear answer to the question of why these changes took place, there is considerable conviction that the previous explanations are implausible and that the problem often has been stated in a way that is no longer coincident with the culture historical data now known. The opening centuries of the second millennium witnessed a transformation of Harappan life, with important changes in the sociocultural system, but the notion of a "decline" an "end" or an "eclipse" no longer seems to capture the historical reality of these times. This paper reviews the principal theories that have been put forth to explain the "eclipse" and offer some, new observations that emerge from recent research on the Harappan Civilization. Suggestions for research that might further clarify the nature and causes of the transformation are also offered here.

Intensive archaeological exploration in India and Pakistan has advanced our knowledge of settlement patterns and site densities in some of the key regions of the Subcontinent. Although there is much survey left to do, some exploration has been done in all of the modern administrative districts that were earlier occupied by Early, Mature, and Post-urban Harappans. Some districts have been explored intensively on foot. While there are more sites to be found, there is some reason to believe that this

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[1] The editors of *Man and Environment* and the author wish to thank Plenum Press and the staff of the *Journal of World Prehistory* for allowing them to reprint this article which appeared in volume 11(4). 425-472

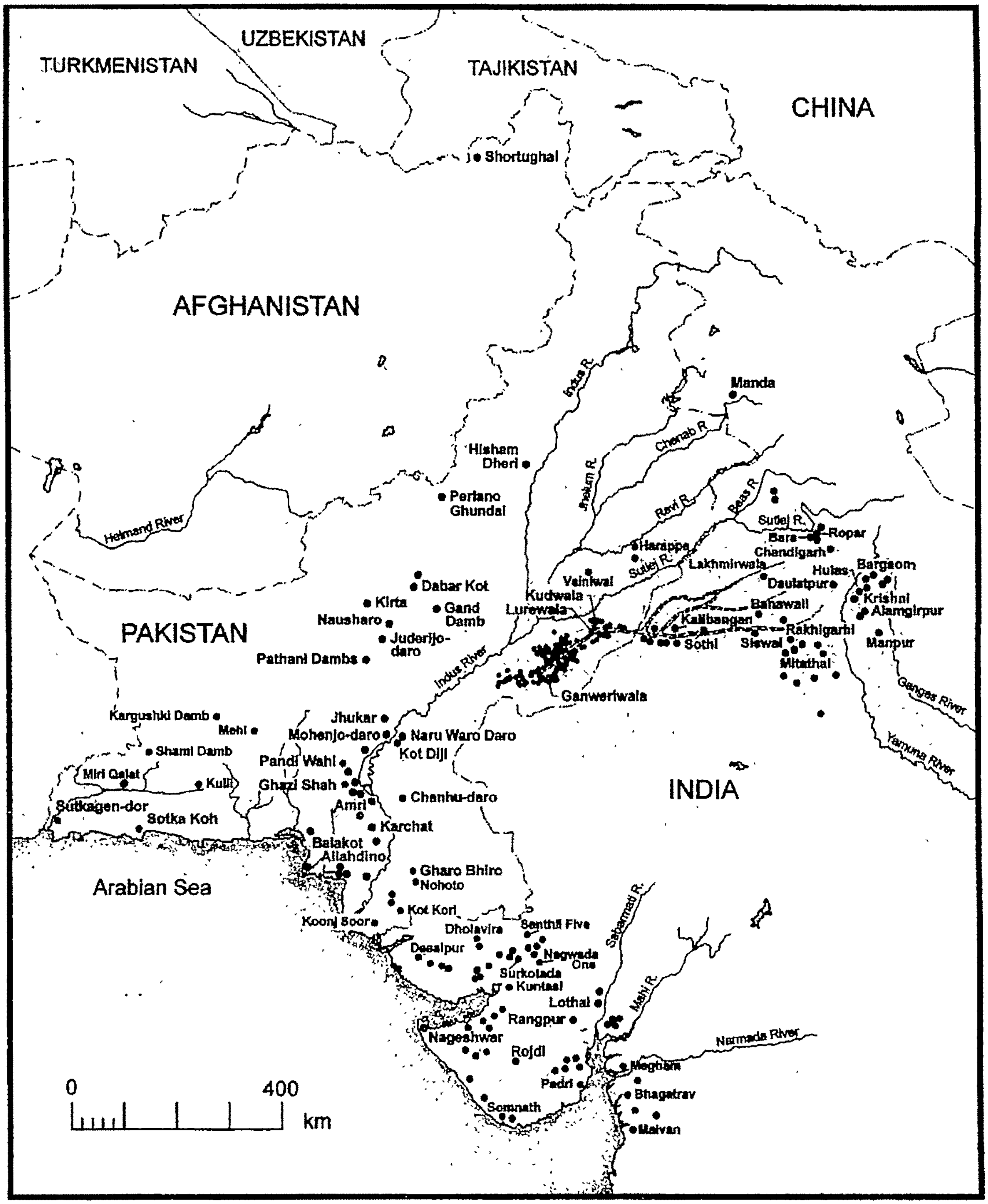

**Fig. 1:** Principal sites of the Mature Harappan

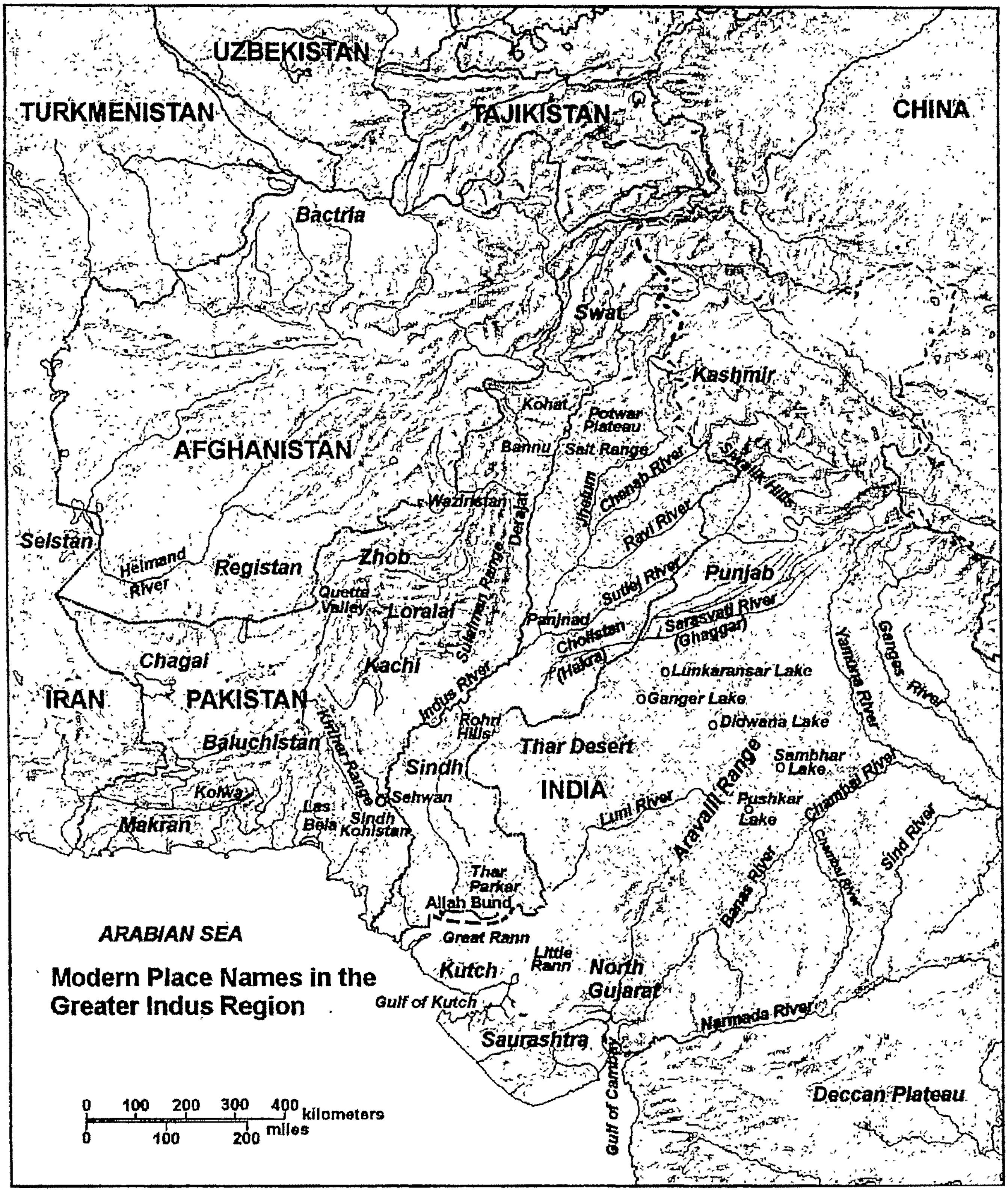

Fig. 2: Geographical names used in the text

work has provided an overall sense of where these ancient peoples lived and the relative densities of sites from district to district. A great deal has been learned from the work of M. Rafique Mughal in Cholistan (Mughal 1997) and Baluchistan (Mughal 1972; de Cardi 1983) and Louis Flam in Sindh Kohistan and the Kirthar Piedmont (Flam 1981) (Fig. 2). The Pakistan Department of Archaeology is currently engaged in the systematic exploration of all of the districts of Sindh and the Punjab. Exploration in India has been vigorously pursued by the Archaeological Survey of India (see especially Joshi *et al.* 1984) and the Indian Universities in the Punjab, Haryana, Uttar Pradesh, and Gujarat. The results of these surveys have been presented in *Indian Archaeology, A Review* and a number of Ph.D. dissertations and Masters theses at Indian universities, many of which have been summarized in sources available to an international audience (Suraj Bhan 1975, Suraj Bhan and Shaffer 1978; Dalal 1980; Dikshit 1987; Bhan 1994). The gazetteer of sites developed by Possehl has documented records on 1022 Mature Harappan settlements: 406 in Pakistan; 616 in India.

The massive amount of archaeological exploration and additional excavation has given a much clearer sense of the culture historical sequence, chronology, and shifts in settlement over time. Data can now be presented on site locations, numbers, and sizes, from the beginning of food production in the Kili Ghul Mohammad Phase (c. 7000-5000 B.C.) through the Post-urban ("Late") Harappan in the middle of the second millennium B.C. (Table 1).

The chronology in Table I and the other dates used in this paper are based on calibrated radiocarbon determinations using the CALIB-3 program. The scheme that emerged from the study of chronology has a linear quality that is a reflection of the fact that all too little is known of this topic. The broad changes between Phases that take place in even hundred year segments are a reflection of the inadequacies of the data, not a model developed by the author. Figures 3, 4, and 5 show the location of all sites for which geographic coordinates are available for the Early, Mature, and Post-urban Harappan. Given this journal's format, it was not possible to include site names with the location.

There is much exploration left to do, and the figures in Table 1 cannot be taken as final. They are a beginning, however, and document the sharp rise in the quality of data available on the Indus Age as a whole, as well as suggesting patterns in the culture historical sequence. The numbers in Table 1 seem to show strong, continuous growth of settlements and population. There is especially noticeable growth between the Togau and the Kechi Beg Phases early in the sequence which might be correlated, in part, with changes in technology and population that have been noted at Mehrgarh in Period III (Hemphill *et al.* 1991: 172-174). The Post-urban Harappan emerges as a period with an increase in the number of sites, but a decrease in the net settled area and average site size, which seems to represent some form of "deurbanization," or a redistribution of the population over the landscape. Both of these processes

**Table 1**: Site Counts, Total Settled Area and Average Site Size for Sites of the Indus Age

| **Phase/Period** | **site counts measured** | **settled area in ha** | **average size in ha** |
|---|---|---|---|
| Post-urban Harappan<br>c. 1900-1400 B.C. | 1281 | 4484 | 3.5 |
| Mature Harappan<br>c. 2500-1900 B.C. | 1022 | 7358 | 7.2 |
| Early/Mature Harappan Transition<br>c. 2600-2500 B.C. | insufficient settlement data | | |
| Early Harappan<br>c. 3200-2600 B.C. | 477 | 2146 | 4.5 |
| Kechi Beg/Hakra Wares<br>c. 3800-3200 B.C. | 256 | 1331 | 5.2 |
| Togau<br>c. 4300-3800 B.C. | 84 | 294 | 3.5 |
| Burj Basket-marked<br>c. 5000-4300 B.C. | 33 | 86 | 2.6 |
| Kili Ghul Mohammad<br>c. 7000-5000 B.C. | 20 | 52 | 2.6 |

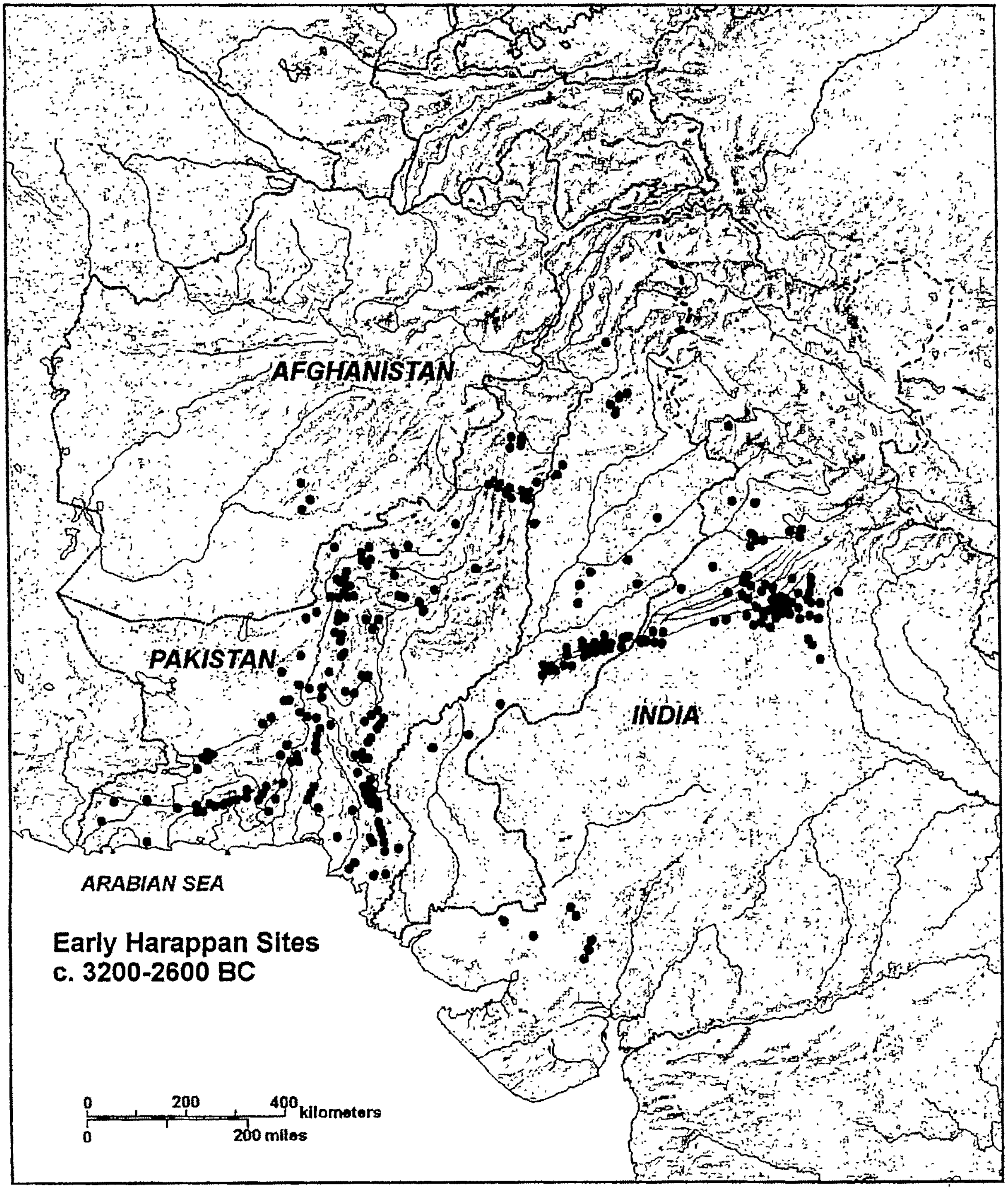

Fig. 3: Sites of the Early Harappan

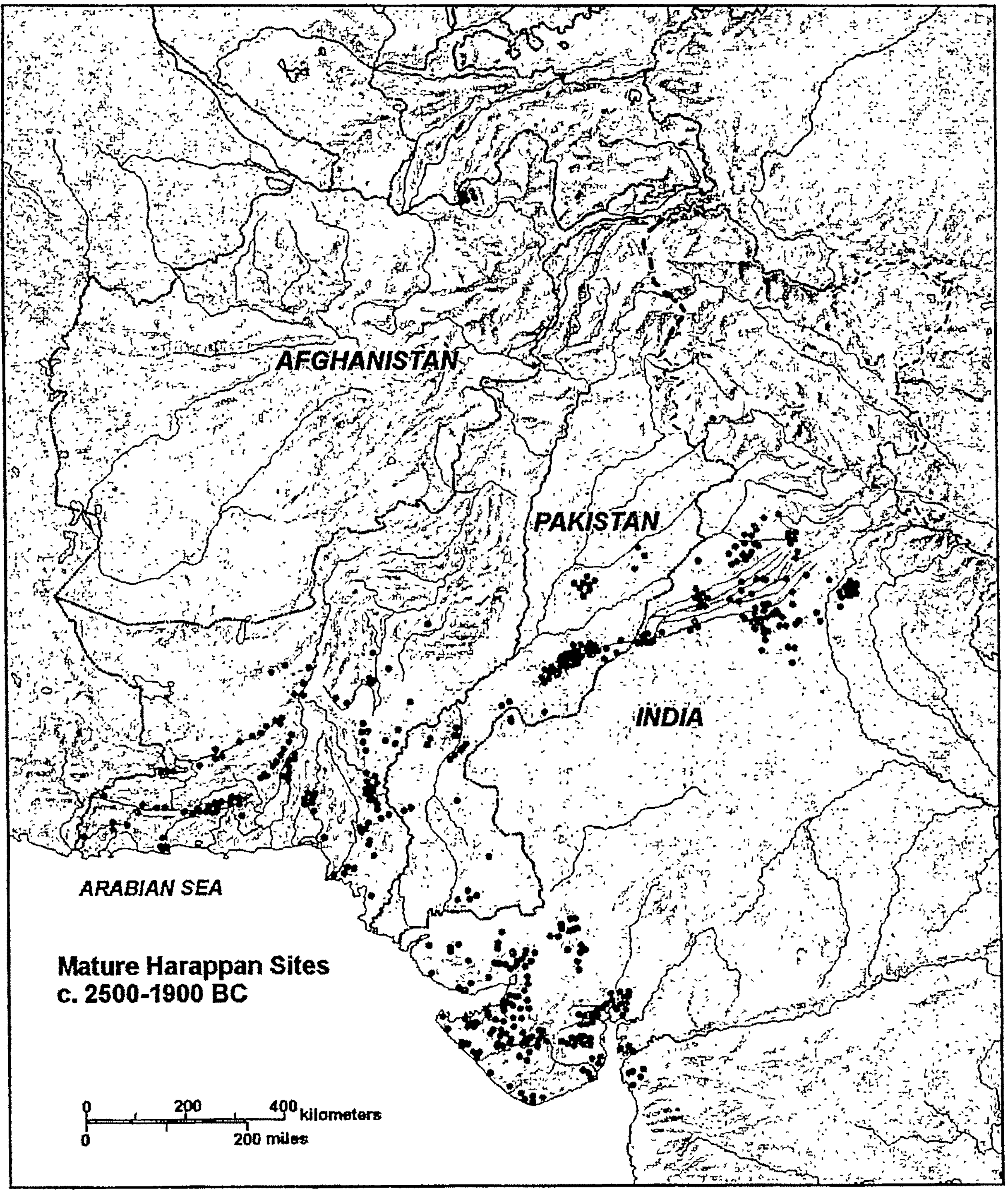

**Fig. 4**: Sites of the Mature Harappan

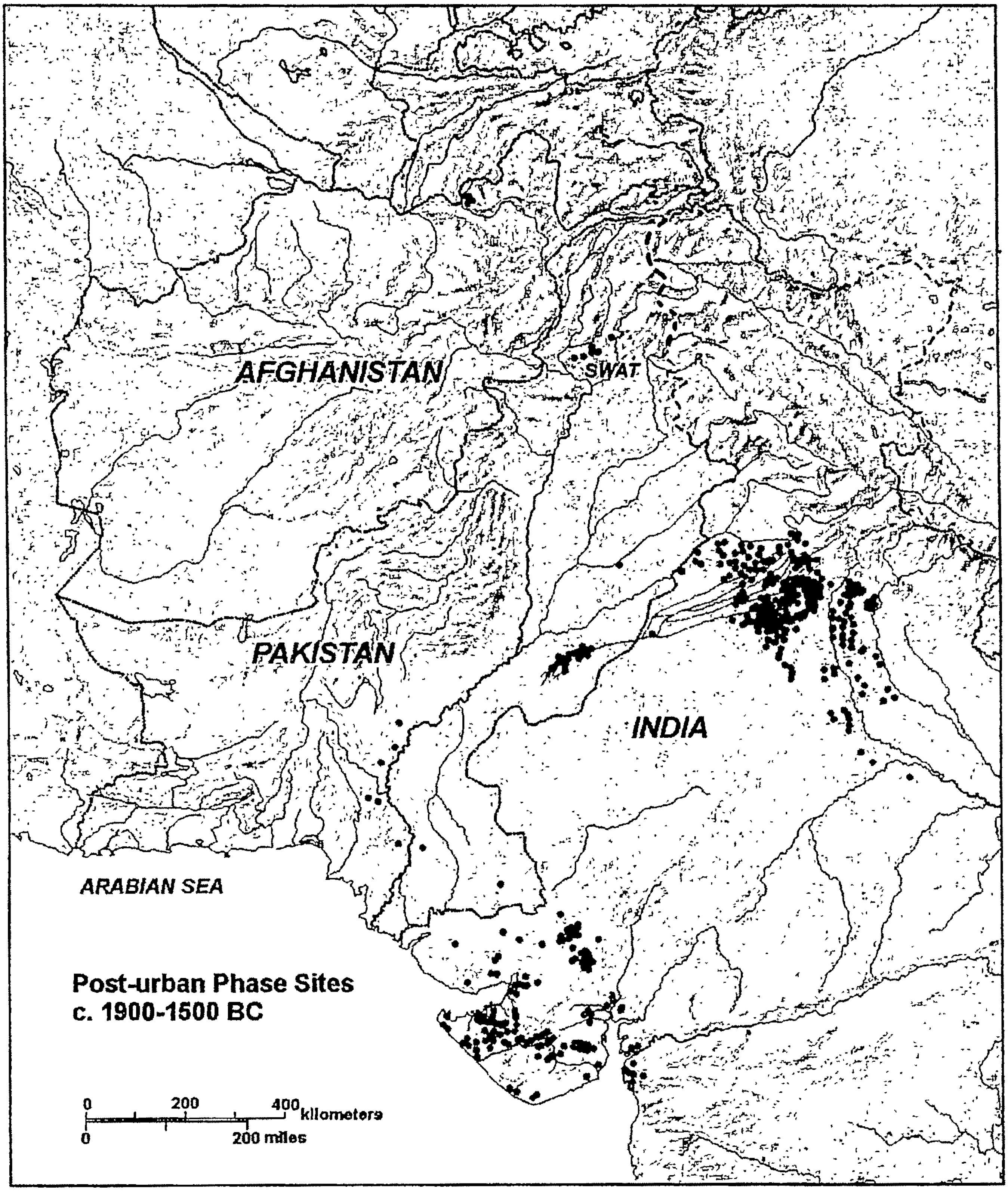

**Fig. 5**: Sites of the Post-urban Harappan

imply substantial changes in the system of settlement and subsistence, as well as important alterations of the political and economic institutions.

Ninety-six sites important to the understanding of the Mature Harappan have been excavated — 41 in Pakistan and 55 in India — so excavation has also proceeded apace. The French research at Mehrgarh has provided a much needed insight into the development of food production in Pakistan (Jarrige *et al.* 1995). Their continued work at Nausharo has shed light on the development of the Mature Harappan (C. Jarrige 1994; J.-F. Jarrige 1993). Ten years of renewed excavation at Harappa has given firmer chronological control over the Indus Civilization from the Early Harappan through the Post-urban Phase Cemetery H assemblage, as well as insights into craft production and some aspects of civic architecture (Meadow 1991; Kenoyer 1993a, b, 1994). Louis Flam's (1993) excavations at Ghazi Shah have furnished chronological information on settlement in the Lake Manchar area, especially with respect to the Early Harappan/Mature Harappan Transition at c. 2600-2500 B.C. Excavations by the Pakistan Department of Archaeology at Sarai Khola, a multi-period site near the ancient city of Taxila, has provided information on an important Early Harappan settlement (Halim 1972a, b). The same is true of the excavations at Rehman Dheri (Durrani 1988; Durrani *et al.* 1991) and in the Bannu Valley (Allchin *et al.* 1981, 1986; Khan *et al.* 1991).

Virtually all of the Mature Harappan sites in India have been excavated since Independence in 1947. The consistent contributors to this effort have been the Archaeological Survey of India, Deccan College, the M.S. University of Baroda, Kurukshetra University, and various State Departments of Archaeology. Major, multi-year excavations at places such as Kalibangan (Thapar 1975; Lal 1977), Hulas (Dikshit 1981, 1982, 1984), Banawali (Bisht 1978, 1982, 1987, 1994), Lothal (Rao 1979, 1985), Rangpur (Rao 1963), Rojdi (Possehl and Raval 1989; Possehl and Mehta 1994), Kuntasi (Dhavalikar *et al.* 1996) and Dholavira (Bisht 1989a, b, 1991) have expanded our knowledge of the Harappan Civilization generally.

### Indus Civilization: the Paradigms of Understanding

These fresh data from exploration and excavation, in addition to the expanded number of scholars working on the South Asian Bronze Age, have led to new perspectives on the Indus Civilization.

### The Old Paradigms: Marshall, Mackay, Wheeler and Piggott

The first Indus paradigm was developed by Sir John Marshall with some contribution from his colleague Ernest J.H. Mackay. Marshall's Harappans were austere, peaceful, urban, merchant burghers, whose beliefs were harbingers of later Indian ideologies. Mackay (1948: 49-50) notes:

> Although in the material used and in the stability and carefulness of their construction these burnt-brick cities were certainly the equal to any later work found in India or elsewhere, they are far from remarkable for beauty, refinement, or decorative value. One house is so like another, with its plain, unrelieved walls, that to the modern eye something seems sadly lacking in the mental and spiritual equipment of the builders. Except for floods and occasional raids, there must have been little to upset the humdrum routine of these busy communities of traders, a state of affairs which doubtless brought about the atrophy of the artistic sensibilities of their members.

After Marshall, the next powerful Director General of the Archaeological Survey of India was Sir Mortimer Wheeler. He was no admirer of Marshall, whose principal defects in Wheeler's (1971) eyes seem to have been, a lack of understanding and appreciation of archaeological stratigraphy and an inability to escape from a kind of cult of personality that developed around him and inhibited change and innovation in the Survey.

Wheeler came to see the Indus Civilization differently from Marshall. He thought of the Mature Harappan as a civilization with priest-kings and a strong sociocultural likeness to Mesopotamia:

> It can no longer be doubted that, whatever the source of their authority — and a dominant religious element may fairly be assumed — the lords of Harappa administered their city in a fashion not remote from that of the priest-kings or governors of Sumer and Akkad. In other words, the social structure of Harappa conformed in principle with that of the three great riverine civilizations of the day (Wheeler, 1947b: 76).

There was also the sameness: "All is orderly and regulated...dull, a trifle lacking in the stimulus of individuality" or the "absence or suppression of personality in its details from street to street" and "this sense of regimentation..." (Wheeler 1950: 28). In another place he refers to the "astonishing *sameness* of the civilization...Another quality of it is its *isolation*" (Wheeler 1950: 29; original italics).

Wheeler's colleague Stuart Piggott follows this line of thought but is more subtle in his treatment of the Mesopotamians. His version of the paradigm is found in his book, *Prehistoric India* (1950: 153). The Harappan Civilization was "a state ruled by priest-kings, wielding autocratic and absolute power from two main seats of government, and with the main artery of communication between the capital cities provided by a great navigable river, seems, then, to be the reasonable deduction from the archaeological evidence of the civilization of Harappa."

V. Gordon Childe took to this new line in the 1953 edition of *New Light on the Ancient East*:

> No multiplication of weapons of war and battle scenes attests internecine conflicts between city states as in Mesopotamia, nor yet the force whereby a single king, as in Egypt, achieved by conquest internal peace... At the moment the two cities of Harappa and Mohenjo-daro stand out like twin capitals in a single "empire" among a number of smaller sites — provincial townships, fortified villages, and possibly frontier posts and factories... That a "ruler" dwelt in the citadels is clear, and the attachment thereto of great granaries concretely expresses his economic power; like the Sumerian city-god or the divine pharaoh he concentrated the real wealth produced by the city's dependent territories.

The "citadels" proposed by Wheeler and Piggott posed a problem for them because there was a distinct lack of evidence for warfare. Where were the arms? Where was the enemy? From whom were the priest-kings protecting themselves? This problem was addressed by Wheeler (1953: 52-53) in the following way:

> The Indus Civilization inevitably derived its wealth from a combination of agriculture and trade. How far these sources were supplemented and enlarged by military conquest is at present beyond conjecture, but it is to be supposed that the wide extent of the civilization was initially the product of something more forcible than peaceful penetration. True, the military element does not loom large amongst the extant remains, but it must be remembered that at present we know almost nothing of the earliest phase of the civilization.

As at present known, fortifications at the two major cities are confined to the citadels; it is not apparent that the Lower City was in either case fenced. This in itself suggests that the function of the armed citadel may have been as much the affirmation of domestic authority as a safeguard against external aggression. Until, however, the negative evidence in respect of the Lower City is stronger than it is at present, too much stress may not be laid upon this interpretation.

There is no evidence for a "fence" around the Lower Town of Mohenjo-daro, although there is some suggestion that part of the southeastern portion of Harappa had a substantial wall and gateway. The Lower Town of Mature Harappan Kalibangan also has a wall around it, but these are exceptions in Mature Harappan town planning. Moreover, walls around settlements are often multifunctional, offering flood protection, defining the limits of settlement, and regulating the comings and goings of people and animals (both wild and domesticated), as well as providing defense.

The problem with envisioning the high mounds at Mohenjo-daro and Harappa as citadels has not improved since 1953, and the concept has been dropped by most modern interpreters of the Harappan Civilization. But, what of the high mounds at Harappa and Mohenjo-daro?

Very little is known of the architecture on the summit of the AB Mound, the "citadel" at Harappa. It is not possible to make definitive remarks on the form of habitation or facilities there, but the Mound of the Great Bath at Mohenjo-daro seems to have been a place of ritual rather than a safeguard against attack (Fig. 6). The elevation of the mound can be taken to mark this space symbolically as auspicious. The water of the Great Bath would then relate to cleanliness, probably both physical and symbolic. The Mound of the Great Bath was also a place for storage, and this brings an important economic function into the domain of the religious establishment. The striking juxtaposition of the tank and an adjacent storage facility at Lothal might be seen as conforming to the Mohenjo-daro

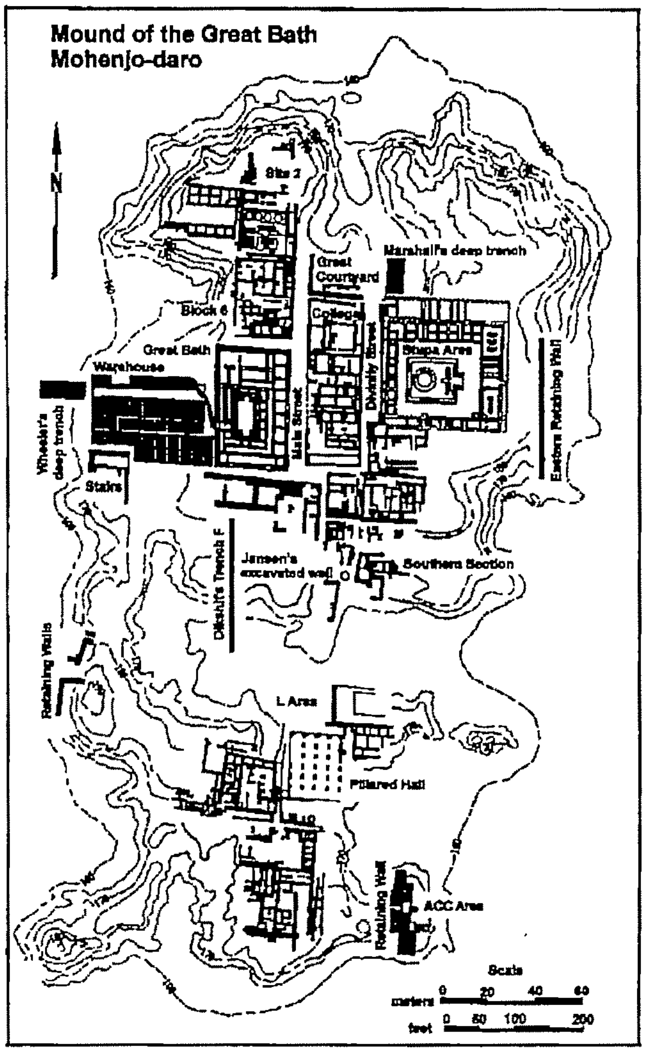

**Fig. 6**: Mound of the Great Bath at Mohenjo-daro

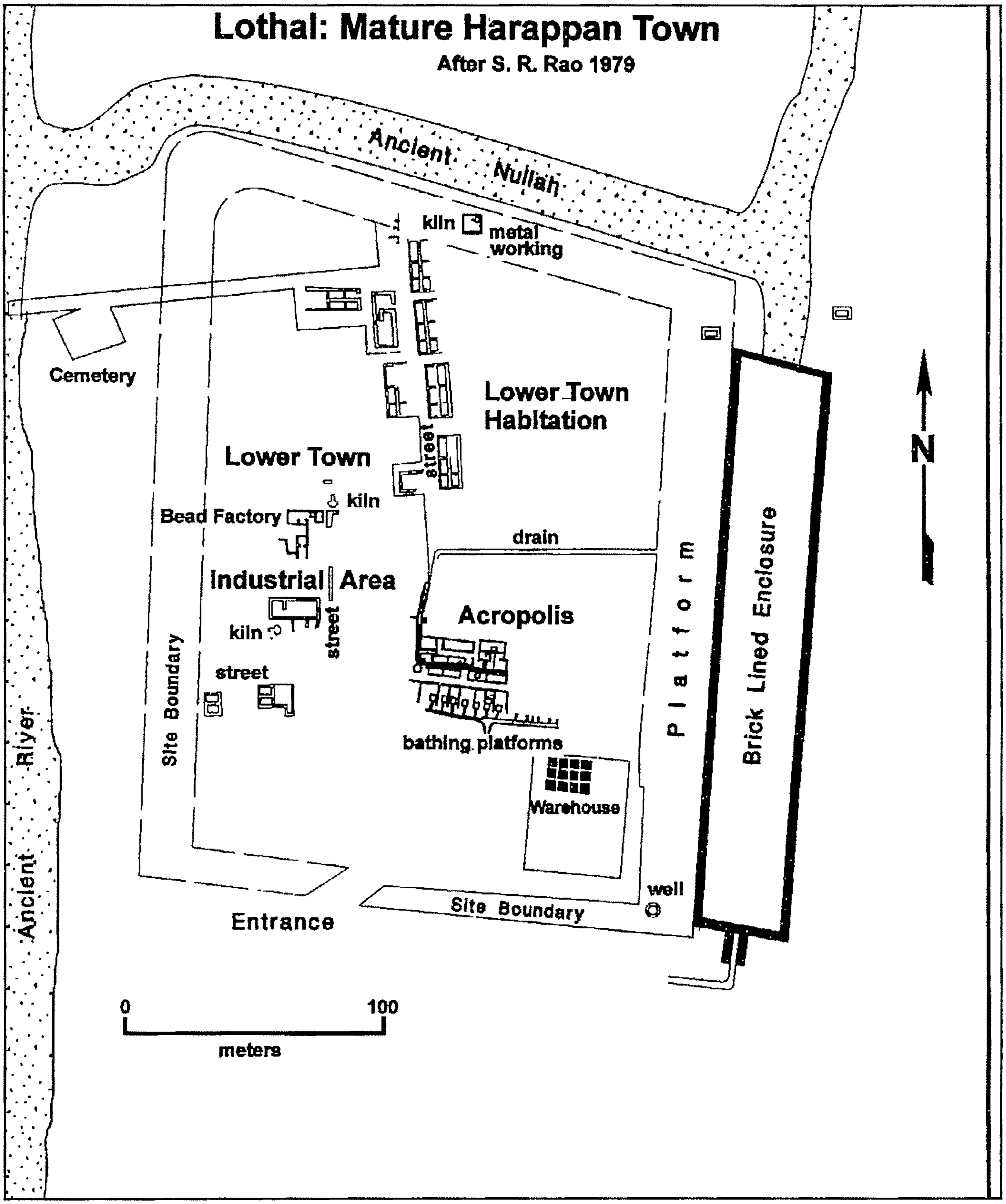

Fig. 7: Plan of Lothal

arrangement (Fig. 7). In the end, the citadels and Harappan priest-kings are now largely artefacts of defunct interpretations, and that is true of the "sameness theme" for Harappan material remains as well.

### *New Paradigms: Interaction, Regionalization, and Transformation*

Contemporary researchers no longer think of the Harappan Civilization in terms of "sameness" and "isolation." Recent work has sought to define regional "polities" (Joshi 1984; Ratnagar 1991; Possehl 1992a) and to understand long distance relationships between ancient India, the Arabian Gulf, the Horn of Africa, the Iranian Plateau, Central Asia, and Mesopotamia (Ratnagar 1981; Potts 1990; Edens 1993; Tosi 1993; Cleuziou and Tosi 1994; Possehl 1996, 1997). What has emerged from this research is the sense that there is a regional mosaic of Early and Mature Harappan remains that can be taken as a proxy for political and possibly ethnic diversity (Fig. 8). The languages spoken by these people, and the details of their social life and organization are not known, but some contemporary

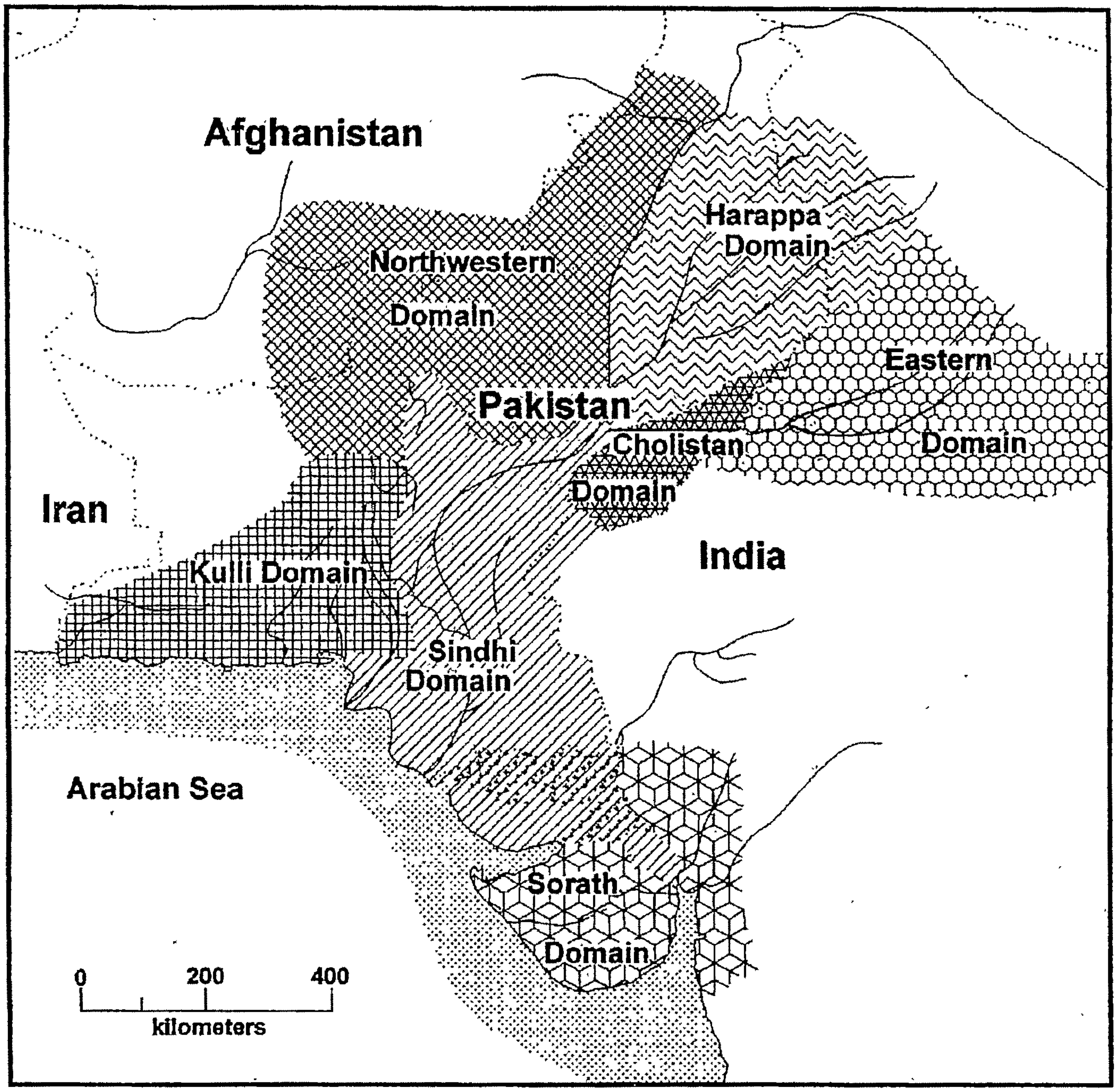

**Fig. 8**: Domains of the Mature Harappan

researchers are of the opinion that the Early Harappan and Mature Indus Civilization represent many kinds of people.

These are themes that go beyond the intended scope of this paper but are developed in the *Indus Age* (Possehl 1998a, b). Let me turn now to the central theme of this paper, the transformation of the Mature Harappan that took place at the opening of the second millennium B.C.

## The Transformation of the Mature Harappan

The abandonment of Mohenjo-daro and many other sites of the Harappan Civilization is a well-known archaeological fact. There is very little documentation of habitation at Mohenjo-daro between c. 1900 B.C. and the Kushana Period in the early centuries of the common era. During the latter time a Buddhist monastery and stupa were built on the Mound of the Great Bath. Many other Mature Harappan sites were forsaken at about 1900 B.C., especially in Sindh and Cholistan. Although the size of Harappa itself was reduced at this time, there were people living there and they maintained the famous "Cemetery H" at the site. Judged by its small size and lack of signs of internal complexity, Harappa was not an urban place during Cemetery H times.

There is now a much better perspective on what took place at the opening of the second millennium, when Mohenjo-daro was deserted than was available to Wheeler and Piggott. This is discussed in detail in Possehl (1996b) and is summarized here:

> There was an abandonment, or severe depopulation, of the cities and a number of important settlements including Kot Diji, Balakot, Allahdino, Kalibangan, Ropar, Surkotada, Dholavira, Desalpur, and Lothal. There was also a disruption in the Mature Harappan economy. Long distance trade was reduced and the production of a wide range of special materials, many of which seem to have been luxury items, was curtailed (e.g., long barrel cylinder beads, etched beads generally, inscribed stamp seals).

The distribution of the human population in northwestern India and Pakistan was changed in a significant way. Sindh and Cholistan were largely abandoned by settled farmers and there was an increase in the number of settlements in the Punjab, Haryana, western Uttar Pradesh, and northern Rajasthan. The Harappans in Gujarat seem to have remained remarkably stable.

There were shifts in the subsistence regime, with a growth in the population's ability to sustain double cropping with the use of millets.

The Mature Harappan style in architecture and material culture disappeared, along with the stamp seals and a coherent system of writing. Post-urban times witness a return to a cultural mosaic not unlike the one found during the Pre-urban Phase (Possehl 1982). Yet, in spite of these changes, some of which seem to be of fundamental significance to Mature Harappan society and those sociocultural issues that lie at the heart of urbanization and sociocultural complexity, there is a strong line of culture historical continuity throughout the Harappan region.

Sir John Marshall has almost nothing to say about the desertion of Mohenjo-daro. His colleague, Ernest J.H. Mackay (1948: 16) believed that Mohenjo-daro might have been abandoned because of an avulsion of the Indus River, which was noted by his wife, Dorothy Mackay (1945), an anthropologist, in another context.

The Indus River in Sindh is a mature stream which frequently changes it course. Much river training has been done on the Indus in modern times, so these course shifts are not as apparent today as they were through the nineteenth and early twentieth centuries. But they are a powerful part of the history of Sindh. Two other archaeologists have followed Mackay's lead, suggesting that a dramatic shift in the course of the Indus led to the abandonment of Mohenjo-daro (Lambrick 1967; Mughal 1990).

An avulsion of the Indus River might explain the abandonment of Mohenjo-daro, but there was a good deal more happening in the greater Indus region at the turn of the third millennium. This leads those who use an avulsion of the Indus and the abandonment of Mohenjo-daro as an element in the transformation of the Harappan Civilization to revert to some form of "domino effect" to account for the "eclipse" generally: "as Mohenjo-daro went, so went the Harappan Civilization." It places a great deal of importance on the place of Mohenjo-daro within the fabric of this civilization, which may not be fully justified. There are a number of other theories concerning the collapse of the Mature Harappan.

## The Post-Urban Harappan: Wheeler's Aryan Army

The first coherent "theory" concerning the eclipse of the Harappans was put forward by Sir Mortimer Wheeler (1947b: 78-83). He held that the Rigveda could be read in part as an historical document and that the conflicts described there were between what he thought of as newly arrived Aryan warriors and the indigenous Harappans. This is stated most clearly in Wheeler's (1947b: 82) report on his 1946 excavations at Harappa:

> The Aryan invasion of the Land of the Seven Rivers, the Punjab and its environs, constantly assume the form of an onslaught upon the walled cities of the aborigines. For these cities the term used in the Rigveda is *pur,* meaning a 'rampart', 'fort' or 'stronghold'. One is called 'broad' (*prithvi*) and 'wide' (*urvi*). Sometimes strongholds are referred to metaphorically as 'of metal' (*ayasi*). 'Autumnal' (*saradi*) forts are also named: 'this may refer to the forts in that season

> being occupied against Aryan attacks or against inundations caused by overflowing rivers' (Macdonell and Keith 1912, Vol. 1: 538). Forts 'with a hundred walls' (*satabhuji*) are mentioned. The citadel may be made of stone (*asmamayi*): alternatively, the use of mud-bricks is perhaps alluded to by the epithet *ama* ('raw', 'unbaked'; Rigveda, IV, xxx, 20 and II, xxxv, 6). Indra, the Aryan war-god, is *puramdara* 'fort-destroyer' (Rigveda II, xx, 7; III, liv, 15). He shatters 'ninety forts' for his Aryan protege, Divodasa (Rigveda I, cxxx, 7). The same forts are doubtless referred to where in other hymns he demolishes variously ninety-nine and a hundred 'ancient castles' of the aboriginal leader Sambar (Rigveda II, xiv, 6; II, xix, 6; IV, xxvi, 3). In brief, he 'rends forts as age consumes a garment' (Rigveda VI, xvi, 13).
>
> Where are — or were — these citadels? It has in the past been supposed that they were mythical, or were merely 'places of refuge against attack, ramparts of hardened earth with palisades and a ditch' (Macdonell and Keith 1912, Vol. 1: 356, 539). The recent excavation of Harappa may be thought to have changed the picture. Here we have a highly evolved civilization of essentially non-Aryan type (Marshall 1931d: 110-112) now known to have employed massive fortifications, and known also to have dominated the river-system of north-western India at a time not distant from the likely period of the earlier Aryan invasions of that region. What destroyed this firmly-settled civilization? Climatic, economic, political deterioration may have weakened it, but its ultimate extinction is more likely to have been completed by deliberate and large-scale destruction. It may be no mere chance that at a late period of Mohenjo-daro men, women and children appear to have been massacred there (Mackay 1937-38, Vol. 1: 94-95; 116-117, 172). On circumstantial evidence, Indra stands accused.

Although Wheeler succeeds in presenting the drama of his theory with "Indra stands accused" as its capstone, this theory can be critiqued from a number of perspectives: chronological, cultural, historical. The chronology of the Aryans in South Asia is far from settled (Allchin 1980, 1990). Although the Vedic Aryans might have entered the Subcontinent well before the composition of the Rig Veda, most scholars now date the codification of this liturgical text to about 1000 B.C., almost a millennium after the transformation of the Mature Harappan. Therefore, no one should assume that the Vedic Aryans were on the scene to be active participants in the transformation process examined here. Also, George Dales (1964) and Kenneth A.R. Kennedy (1982, 1984, 1990, 1994) convincingly argue that the skeletons found in the upper layers of Mohenjo-daro are actually hasty interments, not the remains of victims of a massacre. Finally, the historical content of the Rig Veda has not yet been fully, and convincingly, defined. There is a reasonable supposition that there is important historical information in this liturgical text, but just where within it, and how significant this history might be, is still unsettled.

Krishna Deva and B.B. Lal have told me that the "Aryan hypothesis" seems to have been developed on information Wheeler took from V.S. Agrawala. Agrawala was a member of the Harappa excavation team and had been selected to be the tour guide and lecturer for visiting dignitaries who came to see the excavations. He spoke of the Rig Veda and references in it to warfare and the conquest of towns and cities. Agrawala speculated that this might have been a description of the demise of the Harappan Civilization. Thus, credit for this hypothesis, now dead as an historical notion, seems to belong to Agrawala, not Wheeler.

Another theory, also generally moribund at this time, has a clearer intellectual genealogy, coming from an American hydrologist, Robert Raikes, elaborating an idea first presented by M.R. Sahni (1956).

### *The Raikes/Dales Dam*

The Indus River has reemerged as a dynamic factor in the process of Harappan culture change, due largely to the work of Robert Raikes and G.F. Dales (Raikes 1964, 1965, 1967a, b, 1968, 1979; Raikes and Dales 1977, 1986; Dales 1965a, b, 1966a, b; Dales and Raikes 1968). They hypothesize that the waters of the Indus River were impounded by a natural dam across the river in the vicinity of Sehwan (Fig. 2) and that Mohenjo-daro and other sites were so disrupted that it led to, actually "caused," the abandonment of the city and the eclipse of the Mature Harappan. To support this proposition they claim that the "normal behaviour of a big river simply cannot account for the evidence of massive flooding at Mohenjo-daro" (Raikes and Dales 1986: 33). Even after Raikes presented the scientific data on the sediments (Raikes and Dales 1986; Wasson 1987), there are still a number of critiques of this hypothesis: Lambrick (1967), Possehl (1967), Agrawal (1971: 215-220; 1982: 188-190), and R.J. Wasson (1984, 1987). Wasson has noted that the unconsolidated sediments of the Indus flood plain, which would have been the substance of the dam, have very little structural integrity and could not have withstood the static pressure of the impounded Indus River.

This general notion was first proposed by M.R. Sahni (1956) who noted the presence of thick, bedded alluvium at two hillocks south of Hyderabad, Sindh. This alluvium contained freshwater shells, one of which suggested prolonged submergence in fresh water. Sahni (1956) thought that this thick alluvium might be accounted for by a dam, perhaps at more than one place, across the Indus.

The forming of a large natural dam across the Indus may at first seem so unusual as to be unrealistic. But, in 1819 an earthquake caused the formation of a ridge called the "Allah Bund" in northern Kutch, along the Sindh border, which temporarily dammed the minor eastern courses of the Indus system (Fig. 2). Interestingly, the Allah Bund was breached by the first significant flood against it (Lyell 1853: 462) sustaining Wasson's thoughts that unconsolidated alluvium is not strong enough to impound the Indus, or even its minor extensions.

Another point of disagreement lies in the consideration of historical process. Is it necessary to believe that just because the Indus River was impounded, the Harappan Civilization came to an end? It might be a possibility, but it hardly satisfies the "sufficient and necessary" criteria for successful historical explanation. Even if the waters of the Indus River had been impounded, the historical consequences might have been different from those proposed by Raikes and Dales. The impounding of the river would have to be seen as an immediate cause of change that resonated with some deeper, structural aspect of the Mature Harappan sociocultural system. If the Mature Harappan succumbed to new and unpredicted riverine forces, the explanation sought by historians and social scientists lies not directly with geomorphological matters but, rather, with the internal structure of the Harappan way of life. The "flaw" that would have led to such catastrophic sociocultural change is not to be found within the natural world of geomorphology but within the human context of the Harappan Civilization, its society and culture, as discussed by Possehl (1967: 37-39).

### *Data From the Lost Sarasvati*

Archaeological research along the now largely dry beds of the ancient Sarasvati and Drishadvati Rivers (Stein 1942, 1943; Ghosh 1952, 1953; Dalal 1980; Mughal 1982, 1997) has led to the discovery of a large number of archaeological sites. Sir Aurel Stein's 1943 manuscript has been published by S.P. Gupta (1989). M.R. Mughal's (1997) findings on the Pakistan side of the border represent one of the most impressive archaeological feats of this century in the Subcontinent (Mughal 1997). When placed within the context of the distribution of Harappan sites generally, they lead to a consideration that Cholistan might have been the (or one of the) principal region(s) for Mature Harappan grain production, their "bread basket" as it were. Mughal's findings are the most amenable to quantification at the moment and a long-term trend in settlement counts can be illustrated by using his materials. The data are given in Table 2.

The interface between the Cemetery H assemblage and the Painted Gray Ware has not yet been defined in Pakistan. In India, Painted Gray Ware begins at c. 1100 B.C. The interface between this assemblage and the "Late Harappan" in the Punjab has been documented at places such as Dadheri and Bhagwanpura (see Joshi 1976, 1978, 1993).

The large number of Mature Harappan sites is due to the presence of a rich inland delta in Cholistan, which created a large tract of naturally irrigated land for farming and pasture. Sites of the Early/Mature Harappan Transition, c. 2600-2500 B.C., have not been identified in Cholistan. The chronology for Mughal's periods is taken from the one used here, not from his 1997 monograph, but there is little difference between them.

**Table 2**: Site Counts, Total Settled Area and Average Site Size for Cholistan

| Period | Site counts | Settled area in ha | Average size in ha |
|---|---|---|---|
| Early Iron Age (Painted Gray Ware)<br>c. 1000(?)-500 B.C. | 14 | 36 | 2.6 |
| Post-urban Harappan (Cemetery H)<br>c. 1900-1700(?) B.C. | 50 | 255 | 5.1 |
| Mature Harappan<br>c. 2500-1900 B.C. | 174 | 974 | 5.6 |
| Early Harappan (Kot Dijian)<br>c. 3200-2600 B.C. | 40 | 256 | 6.4 |
| Hakra Wares<br>c. 3800-3200 B.C. | 99 | 643 | 6.5 |

(from Mughal 1997: 40)

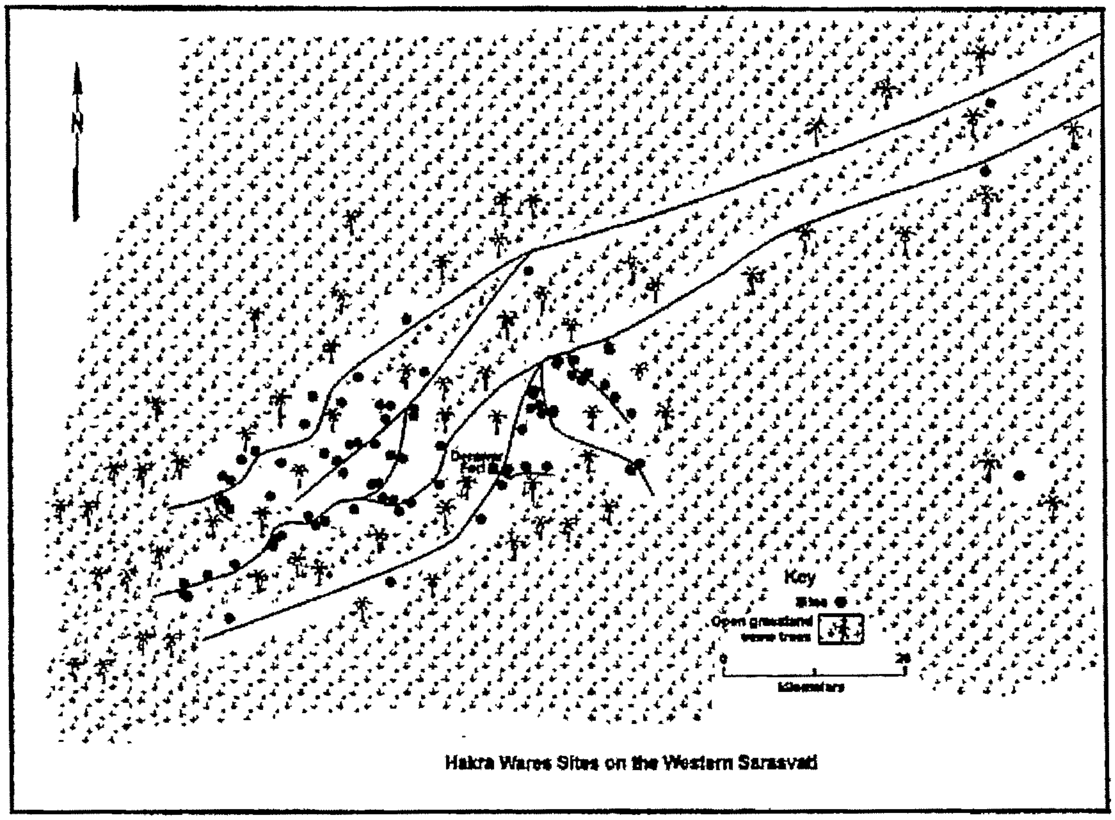
N
Derawar Fort
Key
Sites
Open grassland some trees
0
20
Kilometers
Hakra Wares Sites on the Western Sarasvati

**Fig. 9**: Map of sites of the Hakra Wares Phase in Cholistan

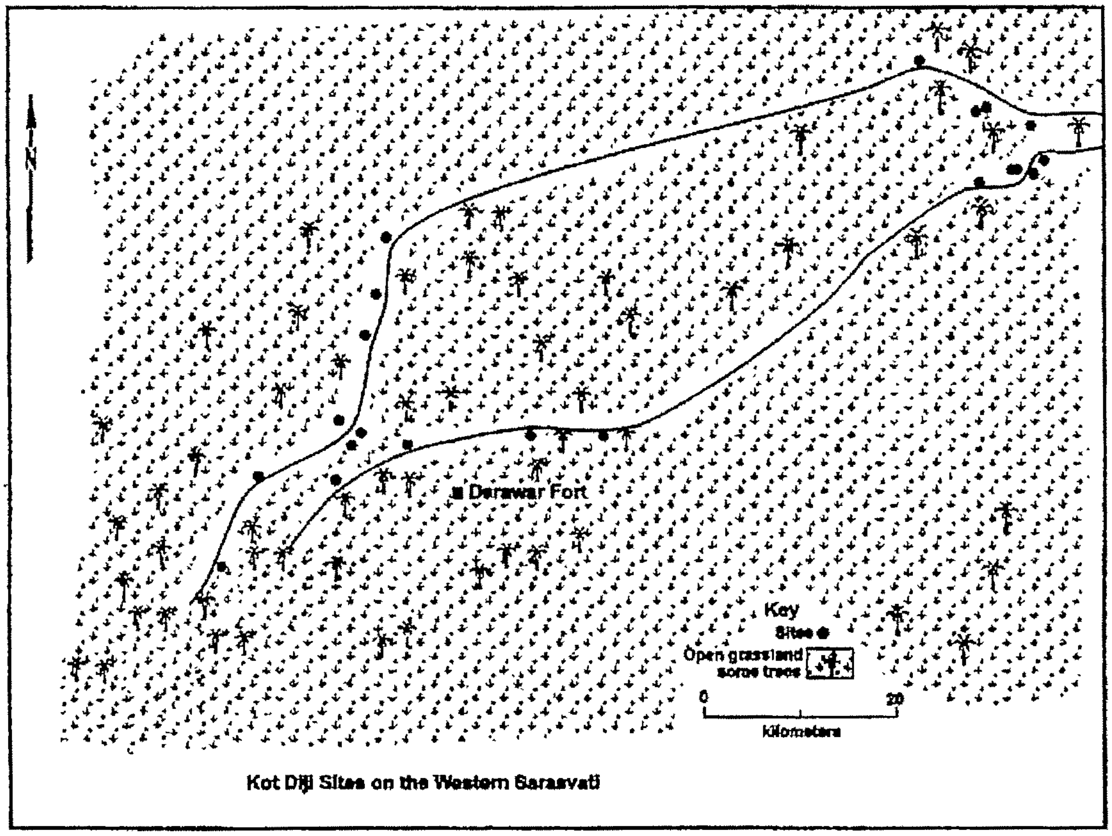
N
Derawar Fort
Key
Sites
Open grassland some trees
0
20
Kilometers
Kot Diji Sites on the Western Sarasvati

**Fig. 10**: Map of sites of the Early Harappan Phase in Cholistan

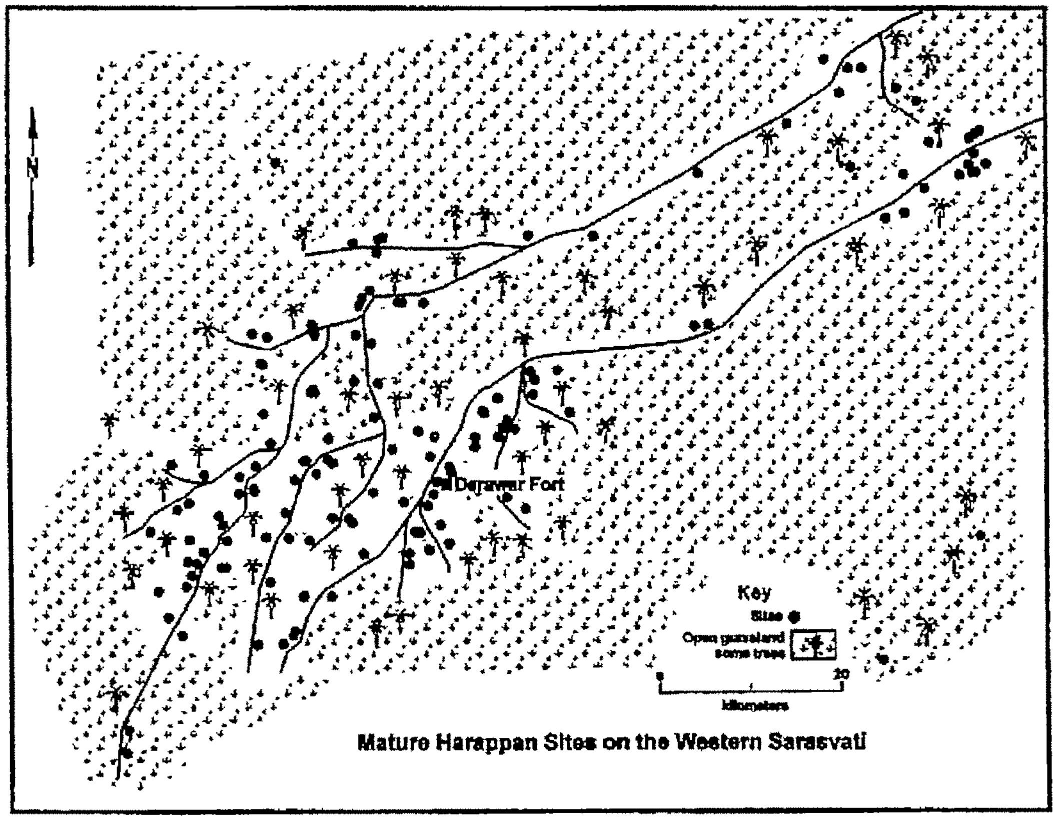
N
Derawar Fort
Key
Sites ●
Open grassland some trees
20
kilometers
Mature Harappan Sites on the Western Sarasvati

**Fig. 11**: Map of sites of the Mature Harappan Phase in Cholistan

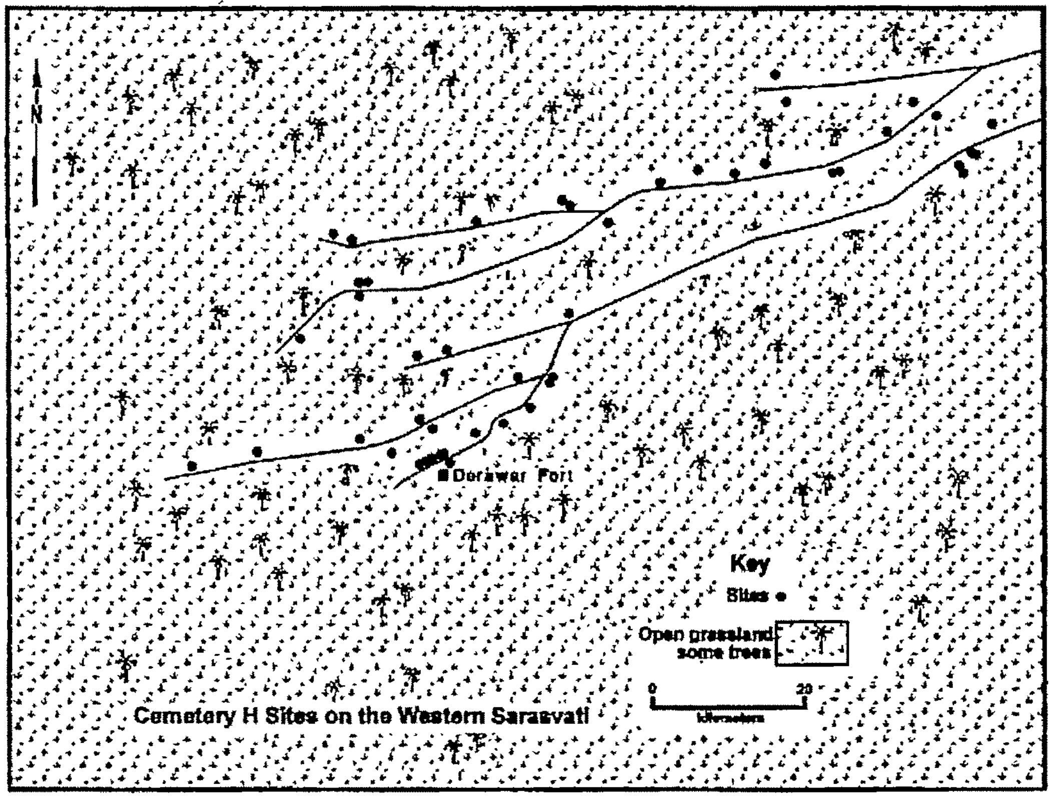
N
Derawar Fort
Key
Sites ●
Open grassland some trees
0
20
kilometers
Cemetery H Sites on the Western Sarasvati

**Fig. 12**: Map of sites of the Cemetery H Phase in Cholistan

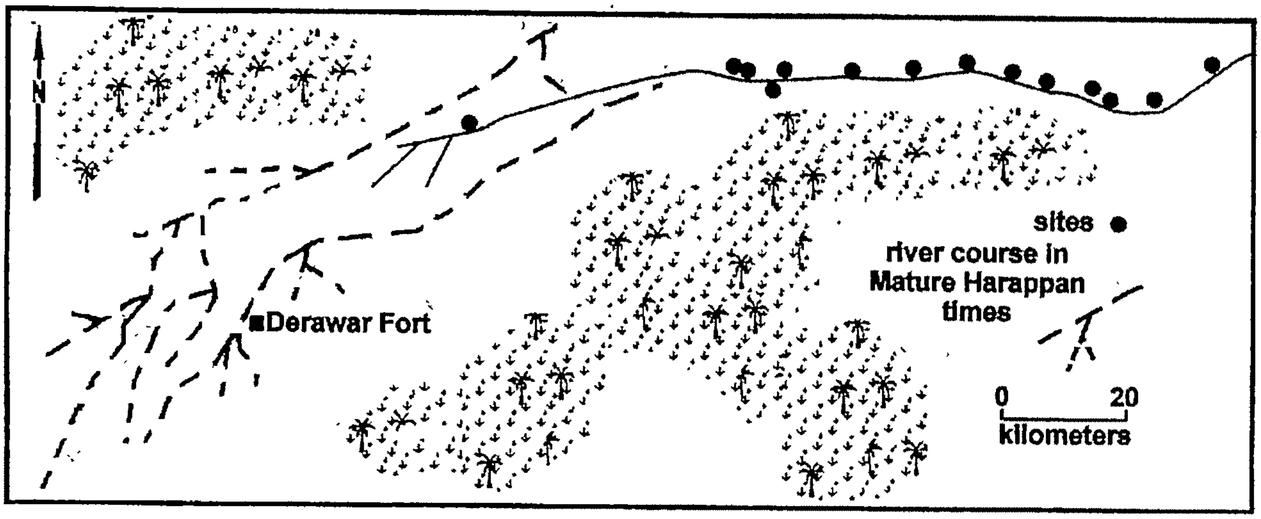

**Fig. 13**: Map of sites of the Painted Grey Ware Phase in Cholistan

The maps of sites from Cholistan seem to give us the broad outlines of the relative strength of flow in the ancient Sarasvati from Hakra Wares times through the Early Iron Age (Fig. 9-13). The relatively high density of the Hakra Wares sites may well inform us of a rather strong flow in the river, which diminished in the next period, with the Early Harappan (Kot Diji) sites being relatively few in number in this area. The very high number of Mature Harappan settlements suggests a resurgence of the river and a rich well-watered inland delta. Then in the Cemetery H and Painted Gray Ware periods we see the two step retreat of the river to the east, eventually with insufficient flow to even reach the old Fort Derawar delta.

The fluvial sequence apparently has little, if anything, to do with broad trends in climatic change but can be explained by tectonics as outlined in Agrawal and Sood (1982). Over what seems to have been the course of the second millennium B.C., waters that drained out of the Himalayan watershed were gradually captured by streams that flowed to the east, into the Bay of Bengal, at the expense of the greater Indus system. This process apparently led to the creation of the Yamuna River, a very young stream, and the drying up of the Sarasvati and Drishadvati Rivers (see also Dikshit 1979; Suraj Bhan 1972; Pande 1977).

This is not to propose that stream capture was the direct cause of the eclipse of the ancient cities of the Indus. A sociocultural cause is sought here, just as with the Raikes-Dales theory of an Indus dam. But, over the course of the third and second millennia, the Sarasvati seems to have dried up, and that seems to have been something that cannot be ignored in a broad consideration of the transformation of the Indus Civilization.

An Indo-French Archaeological Project has also found many sites along the ancient Sarasvati, but on the Indian side of the border. Its findings conform to Mughal's data, including a significant number of Kushan Period sites with the well known, easily recognized Red Polished Ware (Francfort 1986). Francfort (1986: 98) says of the stream capture:

> This shift would have occurred either in the still badly defined Late Harappan period or in the PGW (Painted Gray Ware) period, or gradually during both since Late Harappan (Cemetery H) and PGW sites in the state of Cholistan in Pakistan are found on one of the palaeochannels known locally as Hakra. However, the adoption of this 'hypothesis' poses an interesting methodological problem. If we accept this hypothesis, we ***must*** logically accept as well that another tectonic upheaval would have made the rivers revert to the Kushan (Rang Mahal) period since sites from the latter are again found in the region (original italics).

This is an important statement which Francfort intends to use to sharpen the problem formulation of his team and their colleagues in India (Gentelle 1986; Courty 1986). It is not certain, however, that Francfort's point is really true. That is, ***must*** we accept the same explanation for both data sets: the protohistoric and the early historic (Rang Mahal)? Wars and migrations come about for many reasons, the same is surely true for the regeneration of a settlement grid. For example, technologies unavailable, or unused, in prehistoric times might have been part of the Kushan agricultural regime. Developments like irrigation or the use of bunds for impounding rain water and soil emerge as important new technological features in western India at about the time of the Kushans (Possehl 1975). Such agricultural technology could have allowed renewed settlement in northern Rajasthan, independent and unrelated to tectonics.

### *Gurdip Singh and Climatic Change*

In 1971, Professor Gurdip Singh published a paper reviewing the findings from an investigation of pollen cores from three salt lakes in Rajasthan (Singh 1971; Singh *et al.* 1974): Sambhar, Didwana, and Lunkaransar (Fig. 2). The pollen cores were also associated with several radiocarbon dates and Singh noted an increase in the salinity of the lakes in the early second millennium B.C. He proposed that this increase in salinity was due to increased aridity and that this climatic change could have been the root cause for the eclipse of the Indus Civilization. There has been additional palynological research at these lakes (Singh *et al.* 1972, 1990) and others in Rajasthan (Deotare and Kajale 1996) as well as a long critique (Possehl 1996b). V.N. Misra (1984) has also concluded that the data from the salt lakes of Rajasthan do not provide sound evidence for climatic change.

The changing salinity of these lakes, which appears to be well documented, need not be due to changes in rainfall. The geology and environment of Rajasthan are complex. The three lakes investigated are hypersaline today, but there are also fresh water lakes in this same region (Lakes Pushkar and Ganger; see Fig. 2). This observation leads to the conclusion that, under one climatic regime in Rajasthan, there can be both fresh water and hypersaline lakes, calling into question the Singh hypothesis.

There is some evidence that the salinity of the lakes is controlled by underground drainage, which in turn is controlled by tectonics. When the underground drains are tightly squeezed together and therefore plugged, the only way water can leave the basins is through evaporation, resulting in a buildup of salts. When the subterranean drains are open, there is a regular flow of water and the salts derived from evaporation are carried off in ground water. Tectonics resulting from continental drift and the Subcontinent's collision with the rest of Asia would seem to control the underground drains. Tectonics may also have an important, even controlling, effect on surface drainage.

The Indian Punjab, Haryana, western Uttar Pradesh, and northern Rajasthan (the Eastern Domain) were well settled from Mature Harappan through Post-urban times. Pre-modern agriculture in this area was dependent on rainfall, although some canal irrigation is available today. Some settlement pattern data are presented in Table 3.

Site counts go up from 218 during the Mature Harappan to 853 in Post-urban times (Fig. 4 and 5). Although there was a dramatic drop in average site size, down from 13.54 to 3.55 ha., the estimated total settled area remained remarkably stable for both periods. These data do not look like those that one would expect if there had been a severe reduction in rainfall as Singh proposed, especially given the fact that it is a dry cropping region.

### *The Allchins Approach*

In their most recent book on the archaeology of India, Bridget and Raymond Allchin have an important discussion of the transformation of the Harappan Civilization (1997: 206-222). They hold that:

> ... there are several factors that probably contributed to the abandonment of the urban sites. These include economic factors, particularly the decline of Mesopotamian trade, which had been flourishing up to c. 2000 BC. The reasons for this are unimportant to our discussion, but its decline must have been serious for the Indus cities as, unlike the merchants of Egypt and Mesopotamia, they had no alternative major trading partner to turn to. It would appear that they must have had considerable trade within their own region and its hinterland to fall back on, but this too seems to have been undermined by other causes. In Sindh particularly, and perhaps in other regions to a lesser extent, there was clearly a steady deterioration in the climate and environment. Uplift of the Himalayas due to Plate Tectonics is probably the principal underlying cause of changes in the course of the rivers of the Indus system, as we have outlined in earlier chapters (Allchin and Allchin 1997: 211).

The Allchins approach invokes a series of changes that are coincident and, working together in some yet to be fully understood way, led to the transformation of the Harappan Civilization. This is a sound way to proceed but has some pitfalls. For example, we do not know that there was an interruption of foreign trade with Mesopotamia at c. 2000 B.C. There is little evidence for Mesopotamian products in the Indus during the Mature Harappan, so it is difficult to use evidence from the Post-urban to judge that aspect of commerce. The trade does seem to trickle off at about 2000 B.C., but it may not have stopped. There are many references to Meluhha, the Harappan Civilization, in Mesopotamian texts of the second millennium (Possehl 1996a: 139-144). The Allchin proposal also places a very high value, and critical importance, on Mesopotamian trade vis a vis the Mature Harappan economy. Do we know that it was so important that the termination of trade with the west would have had an impact on the entire civilization? With this proposal also comes the knotty problem of "direction" in causality: did the secession (or reduction) of trade contribute to the transformation of the Harappan Civilization or did the transformation of the Harappan Civilization lead to the secession (or reduction) of the trade? More is said of this international trade in the discussion of the site of Kuntasi, below.

In subsequent pages the Allchins draw heavily on natural forces as causes for the eclipse of the Harappan Civilization (1997: 211-212). They propose that "a reduction of rainfall in Sindh and the immediate hinterland could well have been an added cause for the abandonment of Mohenjo-daro and other urban sites" (1997: 212). But, Mohenjo-daro today receives less than 12 cm (five in.) of annual rainfall and the ancient city today would be in a desert if not for the floods of the Indus. We could take away virtually all of today's rain and still have a viable agro-pastoral environment.

The Allchins wisely state their case for the interconnection of causes in regional and interregional terms. They deal with the greater Indus area as a whole, which is necessary for a complete understanding of the transformation process. But this regional perspective leads to a serious problem. How can we invoke a drop in rainfall in central and northern Rajasthan and still explain the aforementioned large number of Post-urban sites in the Punjab, Haryana, western Uttar Pradesh, and other parts of northern Rajasthan? This is a difficulty with the deteriorating rainfall hypothesis and seems to cast doubt on the entire scheme.

### Was There a Collapse: What Happened?

These observations would seem to bring the entire notion of an eclipse of the Harappan Civilization into question. Where is the collapse or eclipse in the East? Average site size goes down, but based on the data at hand, there is little change in the total settled area. These two observations may indicate a significant reshuffling of the population over the landscape and significant and interesting shifts in subsistence, trade, and the economy generally; but it does not look like "collapse." It does look like lots of people living together in smaller communities. An unattractive, and ungainly notion such as "deurbanization" might capture the transition in the East.

The urban paradigm on which the Mature Harappan was founded, with its large, multifunctional settlements, system of writing, weights and measures, long distance trade and contacts with the Gulf, Africa, Mesopotamia and Central Asia seems not to be a part of the Post-urban Harappan. There is no system of writing in the Post-urban Harappan anywhere, although graffiti from the corpus of Indus signs are found. The cities are no longer functional urban entities. There is an important transformation of Indus life, but this change does not seem to be captured by words such as eclipse or collapse, since there are still large human populations in apparently thriving settlements in may parts of the former Mature Harappan world. For example, there are data from Gujarat that appear to be telling us the same thing.

#### *Gujarat and the Rojdi Excavations*

The renewed excavations at Rojdi in central Saurashtra, in the state of Gujarat (1982-86 and 1992-95), have brought to light substantial portions of this ancient Harappan village (Possehl and Raval 1989; Weber 1991; Possehl and Mehta 1994). Rojdi is a three phase site with continuous occupation from c. 2500-1700 B.C. The latest Phase, Rojdi C, has been dated by calibrated radiocarbon determinations to 2000-1700 B.C. It plays an important role in documenting central Saurashtra at the time of the transformation of the Harappan Civilization.

Extensive and intensive exploration in Gujarat by the Archaeological Survey of India, Gujarat State Department of Archaeology, M.S. University of Baroda and Deccan College has also given us important data on settlement location and size during the Harappan occupation of this "provincial" region. These data are also important to understanding the transformation there. The Harappan sites in Gujarat are now generally referred to as the Sorath

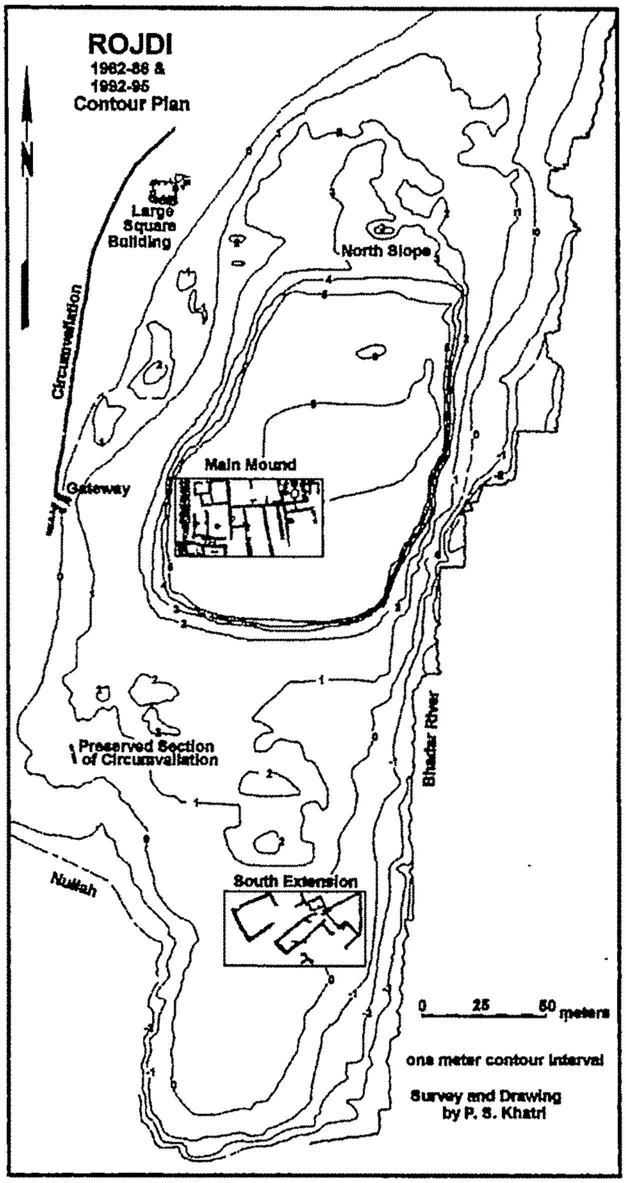

**Fig. 14**: Contour plan of Rojdi

Harappan, reflecting the regional aspect of the Harappan Civilization there (Possehl and Herman 1990; Possehl 1992b).

The earliest phase of occupation, Rojdi A, has been dated to c. 2500-2200 B.C. by a series of eight radiocarbon dates. This settlement was confined to the Main Mound area (Fig. 14). Habitation debris, grain storage structures and one hearth, document that this was the locus of village life at the site at this time. Rojdi A ceramics in trash pits are a clear indication that the South Extension was a land fill. The same is true for the North Slope.

The trash pits and filling continued on the South Extension and North Slope during Rojdi B times. This phase is dated to 2200-2000 B.C. by four radiocarbon dates. Habitation of the Main Mound continued with new construction and the first documentation of stone walls at the site.

The best documented occupation is that of Rojdi C (c. 2000-1700 B.C.). The South Extension became an area of habitation with what seems to have been a single, preconceived building plan (Fig. 15). This addition increased the size of the settlement by about two hectares, or about one-third. There was at least one major remodeling of the South Extension "suburb" in Rojdi C times.

A major structure was also built adjacent to the North Slope in Rojdi C times. This is called the "Large Square Building." Its function is not known, but when it was abandoned, late in Rojdi C, it was filled with the sherds from a large number of storage jars of Rojdi C style.

There is an outer wall, called the "Circumvallation," which had a large gateway and extended all along the western side of the site, including the South Extension. Because it is believed that the inhabitants of the site would not have put such a wall around their land fill, the Circumvallation is dated to Rojdi C, when the village was extended onto this area. The Circumvallation is not a substantial wall. It is only about 1.5 m thick at the base, and not completely filled with stone, even at the foundations. The buttresses at the gateway also face inward and could not have been used as defensive facilities. It seems then that the Circumvallation was intended to demarcate the Rojdi village, was useful in controlling the movement of animals, both wild and domestic, and would have afforded some protection against floods.

Rojdi C times also saw a complete rebuilding of the Main Mound settlement, at least in the major excavation area that was exposed (Fig. 16). This represents a large investment in this settlement, especially since it took place at about the same time that the South Extension was occupied and the Circumvallation and Large Square Building were constructed.

What about the broader picture of the Sorath Harappan in Rojdi C times? Some settlement data on this subject are presented in Table 4.

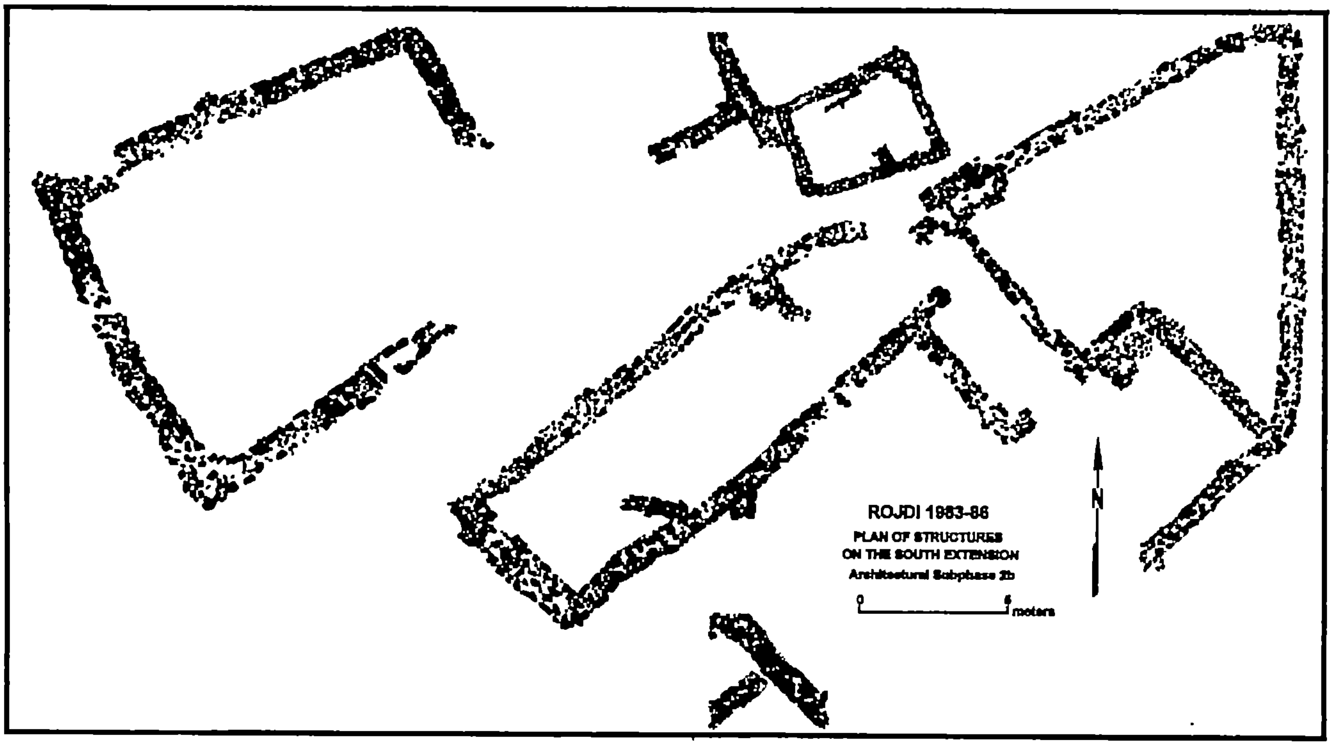

**Fig. 15**: Architecture of Rojdi C on the South Extension

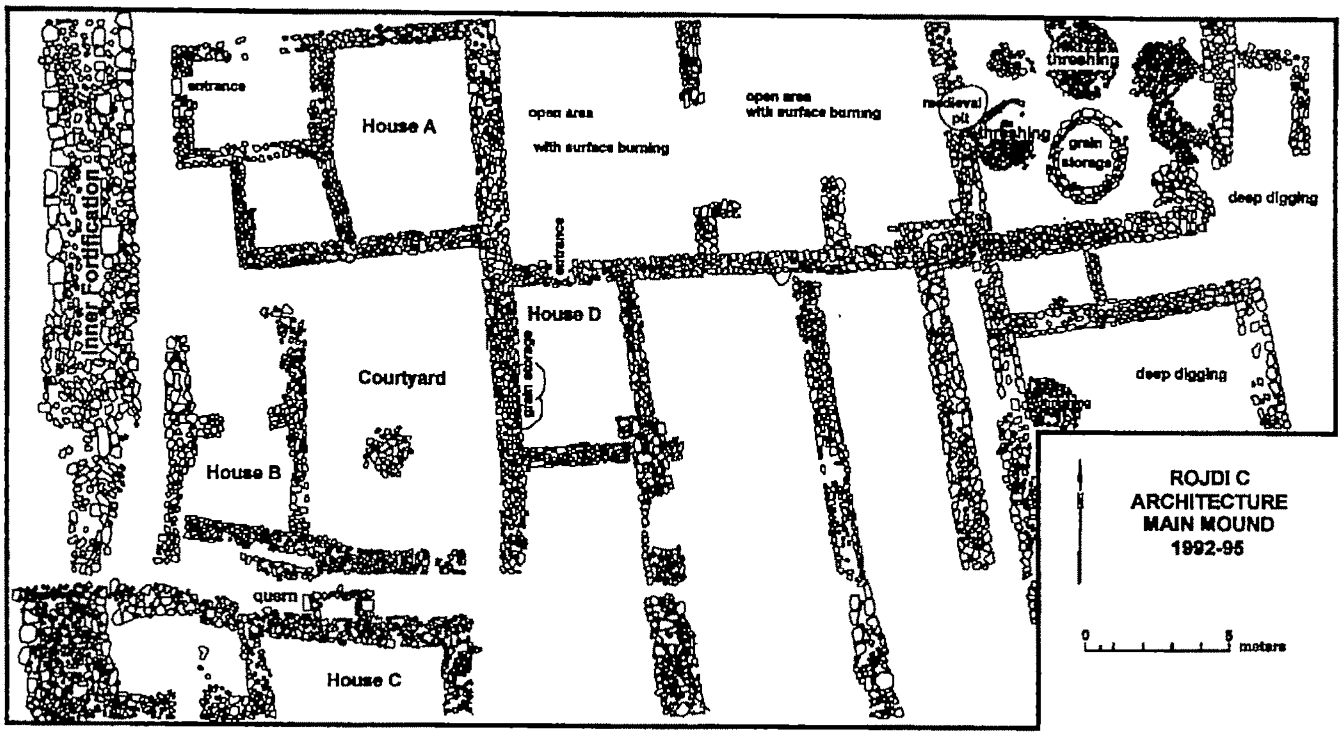

Fig. 16: Architecture of Rojdi C on the Main Mound

**Table 3**: Estimate of Settled Area for the Mature and Post-urban Harappan in the East

| | Mature Harappan | Post-urban Harappan |
|---|---|---|
| Total Sites | 218 | 853 |
| Average Site Size in ha | 13.5 | 3.5 |
| Estimated Total Settled Area in ha | 2943 | 2985 |

**Table 4**: Estimate of Settled Area for Sites of Rojdi A & B and Rojdi C in Saurashtra

| | Rojdi A & B | Rojdi C |
|---|---|---|
| Total Sites | 310 | 198 |
| Average Site Size in HA | 5.4 | 4.3 |
| Estimated Total Settled Area in Ha | 1674 | 851 |

It can be seen in these data that the number of sites drops by one-third and there is a significant drop in the average size of sites. Total settled area, as determined from the settlement surveys, is cut in half. These are robust indicators of deep change in the system of settlement and, probably, substance and the sociocultural system generally. But there is another theme in the transformation process in Saurashtra. At Rojdi the site was expanded and rebuilt just at the time Mohenjo-daro was being abandoned, and Harappa came to an end as an urban centre. Thus, while we have evidence for fewer and smaller villages, at least some of those that survived have signs of a sound economic base and a population that was able and willing to make significant investments in their community.

*Other sites in Gujarat*

It would be wrong to interpret the culture history of Saurashtra, let alone Gujarat, from the relatively modest excavations at Rojdi. One site cannot represent the events or culture historical trends in the entire region. There are interesting and important contrasts to the Rojdi data that have come to light at three other sites in the region: Lothal, Kuntasi, and Dholavira.

Lothal, located near the head of the Gulf of Cambay in a low-lying, old deltaic area of the Sabarmati River, is one of the most famous archaeological sites in India. It was excavated by S.R. Rao of the Archaeological Survey of India from 1954 to 1963. Lothal is a small, 4.8 ha, site that was a centre of trade and manufacturing during Mature Harappan times (Rao 1979, 1985; Possehl 1976; Possehl and Kennedy 1979). Based on the cultural geography of Gujarat during the Mature Harappan, as well as finds from Lothal, this site should be seen as a gateway settlement of the Sindhi Harappans. It was a kind of colony or trading post established by the Harappans of Sindh to gain access to the raw materials of Gujarat, possibly even western India generally. In that sense it was a dependency, perhaps even possibly a colony, of the Mature Harappans in Sindh. This was a very tight, intimate relationship, possibly akin to the kind of relationship that existed between Hudson's Bay trading posts and the parent company.

At about 1900 B.C., Lothal underwent a transformation (Rao 1979: 33). The signs of manufacturing and trade disappeared, and Lothal shrank from its original size to a squatter's settlement near the highest point of the site. The excavator believes that a very large, catastrophic flood was the cause of these changes (Rao 1979: 33-34), but the date and the close relationship with Sindh seem to argue differently. Rather than having been brought to an end because of a flood, Lothal probably came to an end when the infrastructure of Sindh, needed to support it, collapsed.

Kuntasi is another Sorath Harappan site. It is located in Rajkot District, about 130 km north of Rojdi. Kuntasi was excavated by a joint team from Deccan College and the Gujarat State Department of Archaeology for three seasons between 1987 and 1990 (Dhavalikar *et al.* 1996). The excavators believe that this small, 3.3 ha, site was not an agricultural village but was a settlement deeply embedded in Mature Harappan interregional trade (Dhavalikar 1993, 1996).

The first structural phase at Kuntasi belongs to the period when a few structures were built probably for storing the raw materials acquired from the local people; they were later transported to Sindh for processing into finished products. The Harappan trade with West Asia received a tremendous boost in c. 2350 B.C. under Sargon of Agade, as there arose a great demand for luxury articles like carnelian beads, ivory, shell, lapis lazuli and so on... merchant-traders began to migrate in large numbers to Saurashtra in the 23rd cent. B.C. A little later around 2200 B.C., when Mohenjodaro, the most important Harappan centre, was threatened by the danger of Indus floods, the number of Harappan migrants swelled. This would explain why most of the Late Mature Phase (c. 2200-2000 B.C.) settlements were located in the fertile river basins of Saurashtra. Saurashtra was anciently known as Saurashtra — fertile country, because of its large tracts of rich black cotton soil known for its capacity to retain moisture for a long time. Although these were basically agricultural settlements, they may have aided in the acquisition of raw materials and some centres like Kuntasi began to manufacture finished goods during this phase.

It was during the Late Mature phase that the Harappan settlement at Kuntasi was developed into an industrial centre and a port. Kuntasi could not have been an agricultural settlement for the simple reason that even potable water is not available at the site. The geomorphological investigations indicate that the sea, which is now 4 km away, was very near the site and even as late as the 18th century.

The structure complex unearthed at Kuntasi is unique and the evidence allows us to identify the Harappan settlement as an industrial centre for manufacturing pottery and a variety of beads as also probably copper artifacts. The structure complex recalls to the mind the buildings at Surkotada, Desalpur and Pabumath. Of these, Surkotada has been excavated on a large scale and can be identified as a garrison-depot (Soundara Rajan 1984) for providing halting and storage facilities to the itinerant Harappan traders from Sindh. The structures at Desalpur and Pabumath, may not have been very different in nature, but have not been exposed on a large scale (Dhavalikar 1996: 372).

At about 1900 B.C. the same thing that happened at Lothal took place at Kuntasi. The settlement shrank in size and signs of craft activity and trade were reduced. As Dhavalikar (1996: 374-375) notes:

> The Late Harappan occupation at Kuntasi betrays a marked degeneration in the economic activity. People lived in flimsy structures with rubble foundation, mud walls and thatched roofs. Only a few artisans were working. The quality of life had certainly changed for worse, but not the quality of pottery. As already noted, there is not much difference in the pottery from Period I and that from Period II. But they do not seem to have had enough clientele and after surviving for a couple of centuries the site was abandoned in c. 1700 B.C.

Once again, we see a centre of craft and trade in Gujarat, closely tied to Sindh — a dependency relationship — fall prey to the same history as the Sindhis. Dhavalikar has suggested a multifaceted theory, or hypothesis, on the transformation of the Harappan Civilization as part of this work at Kuntasi. It has not been fully developed but is summarized in the report on the Kuntasi excavations as the following.

> The beginning of the second millennium marks a decline in the Harappan activity. The main cause that has generally been cited is the decline in trade with West Asia. This phenomenon was not confined only to Gujarat but in other parts of the Old World there is a marked deterioration. When the decline begins in West Asia, the Indus civilization also received a setback. It was a period of

stress and strain and drastic change in climate and foreign invasions were among the important causes. Everywhere devastating changes were taking place; one of the causes was a shift in climate which was becoming more and more arid leading gradually to desiccation and consequent desertification of the once fertile regions in West Asia. This affected the agricultural production adversely as also trade. It is no sheer coincidence that almost simultaneously with West Asia in India too, the great Indus civilization should be on the decline. Meluhha, which in all probability was Kutch and Saurashtra (Dhavalikar 1997) which figured in the Mesopotamian documents earlier, is hardly mentioned now. The imports from Meluhha decrease and this certainly affected the economy of the Harappans in Gujarat. Industrial centres received a setback from which they never seem to have recovered. The prosperity of the Harappans was now a thing of the past and the post- urban phase is marked by rural settlements which are far too few in number as compared to the Late Mature Phase settlements. Many people seem to have resorted to a nomadic existence and subsisted on hunting-gathering as the evidence from sites like Kanewal and Ratanpura would show (Bhan 1989) (Dhavalikar 1996: 374).

The difficulties inherent in using the termination or reduction of international trade as an explanation for the transformation of the Harappan Civilization have already been noted. In fact, there is no evidence that Mature Harappan trade with Mesopotamia was ever on a scale that could have compromised the integrity of the entire Mature Harappan economic system. I once toyed with this idea (Possehl 1986: 105-109), and it seemed so unrealistic that it could not be developed into a full hypothesis. The notion that there was severe, even measurable, climatic change in western India and Pakistan at the beginning of the second millennium has already been found wanting.

The last site in Gujarat that needs to be examined is Dholavira, the large (60 ha) site on Kadir Island in the Great Rann of Kutch (Bisht 1989a, b, 1991, 1994; IAR 1990-1991: 10-12; 1991-92: 26-35). Dholavira began as a relatively modest settlement in the later Early Harappan or the Early/Mature Harappan Transition. Periods II and III document a full, Mature Harappan town, possibly even a city, with the full inventory of Mature Harappan finds. The inhabitants of the site also express the Mature Harappan proclivities for water management in an exquisite way (Bisht 1994). At about 1900 B.C. the site shrank drastically, with habitation confined to its highest points. There is a good deal of evidence for people destroying earlier architecture and disrupting the old metropolis. Some of the Post-urban occupants lived in circular huts, which are not a Mature Harappan architectural form. Bisht also notes that many Mature Harappan elements continue into the Dholavira Post-urban, including some ceramics, terracotta cakes, and weights although in a "somewhat transformed form" (IAR 1990-1991: 12). In this same passage Bisht notes the presence of Jhukar ceramics at the site.

Lothal, Kuntasi, and Dholavira were essentially "colonies" or dependencies of the Sindhi Harappans. This seems to have made them vulnerable to severe change at the beginning of the Post-urban Harappan. Rojdi and other places that were farming communities, not deeply involved in the acquisition and processing of materials or in the transport that was part of the commerce, were buffered, protected and insulated from the catastrophic changes in Sindh. Places such as Dholavira, Kuntasi, and Lothal succumbed to a kind of domino effect based on the changes in Sindh. The hypothesis that emerges suggests that the tighter the integration the Gujarati or Sorath site had with respect to the Sindhi economy and Sindhi dependence, the greater the impact of the processes of devolution that engulfed Mohenjo-daro and other sites in Sindh.

### *Other Regions*

What of Sindh, the West Punjab, and Baluchistan with regard to the Transformation of the Harappan Civilization? There was the abandonment of Mohenjo-daro, but this is the culmination of a process of civic deterioration that may have a time depth reaching a century or more back into the history of that city.

There is a sequence that can be pieced together for the chronology of the Great Bath and Warehouse at Mohenjo-daro. At an early time in the history of Mohenjo-daro, but within the Mature Harappan, there were settlers near plain level under the Mound of the Great Bath. The inhabitants then raised a platform some six meters high and equipped it with proper bastions and reinforcing. One of the buildings that was constructed at that time was the Warehouse. After this they built their Great Bath. Both the Warehouse and the Bath were abandoned while Mohenjo-daro was still a functioning urban centre, possibly at c. 2200 B.C. The beginning of the end of Mohenjo-daro can be placed here, far removed in time from the eventual abandonment of the city. In the desertion of these two facilities can be seen the initial outward signs that the Harappan Civilization was deeply troubled, no longer able to maintain its initial investments in urban facilities.

Data on settlement that are comparable to those from other regions already presented are given in Table 5.

The documentation of settlement in Sindh during the Jhukar period, the Post-urban there, seems to record significant change. The drop from 86 to 6 sites is important, but so too, is the abandonment, or virtual abandonment, of Mohenjo-daro, the premier urban centre.

Kachi, a low-lying area, has been politically a part of Baluchistan since the early eighteenth century; geographi-

**Table 5**: Estimate of Settled Area for Sites in Sindh

| | Mature Harappan | Jhukar (Post-urban) |
|---|---|---|
| Total Sites | 86 | 6 |
| Average Site Size in Ha | 8.0 | 5.6 |
| Estimated Total Settled Area in Ha | 688 | 34 |

cally it is part of the Indus plains and Sindh. Excavations at the site of Pirak (Jarrige and Santoni 1979; Enault 1979) have shown that this settlement probably began sometime in the early second millennium, although the radiocarbon dates are not coherent. There is cultural continuity at Pirak through to Period III, which is associated with iron.

The Pirak assemblage seems to be foreign to the Kachi region and lies outside the cultural traditions of the Indus Age. There are four or five other Pirak type sites in Kachi, and there may be others in the Quetta-Pishin area of the uplands. Little is known at this time of the broader cultural patterns and distribution of the people who made and used the Pirak type material, but there was apparently a limited amount of settlement in Kachi following the abandonment of Mohenjo-daro.

Settlement data from Baluchistan are also revealing, as shown in Table 6.

It is possible that archaeologists have not properly identified the archaeological assemblage in Baluchistan that dates to the early second millennium. The data presented in Table 6 might then be more an artefact of our ignorance than of an historical observation. Only more work in this region can resolve this problem. For the moment it appears that Baluchistan in Post-urban times was the most severely affected of the regions that once made up the Harappan Civilization.

**Table 6**: Estimate of Settled Area for Sites in Baluchistan

| | Kulli/Quetta Phases 2500-1900 B.C. | Post-urban |
|---|---|---|
| Total Sites | 129 | 0 |
| Average Site Size in Ha | 5.8 | 0 |
| Estimated Total Settled Area in Ha | 748 | 0 |

This region seems to have been the most severely influenced by the transformation processes. There is no documentation for a Post-urban Harappan in Baluchistan. There are three places there with signs of human activity: Mehi (Stein 1931: 153-163), Kulli (Stein 1931: 118-127), and the "Elite Burial" in Quetta City (Jarrige and Hassan 1989). These are places where the so-called "Bactria-Margiana Archaeological Complex" (BMAC) has been found (Hiebert 1994). The signs of human activity that are present are not settlements in the conventional sense. One is an internment: a cenotaph. The others are stray artefacts and signs of cremation within an uncertain, probably much disturbed, context. The BMAC extends onto the plains in Kachi at the Sibri Cemetery (Santoni 1984) and Dauda Damb (Jarrige 1994: 295-296). Together, these archaeological signatures seem to reflect the presence of mobile, nomadic peoples of the early second millennium whose home might well have been Bactria and Margiana far to the north. The historical nature of the presence of the BMAC peoples is not understood. It does not come to us as a robust archaeological signature, but there is enough for me to believe that they were in the Subcontinent.

The settlement patterns around Harappa are not well enough known at this point for the data at hand to be comparable to those for other regions. The Pakistan Department of Archaeology and Rita Wright are currently engaged in an active program of exploration to rectify this. For now, we know that Harappa shrank in size at the beginning of the second millennium. The archaeological assemblage that succeeds the Mature Harappan is the so-called Cemetery H material. Wheeler (1947a: 70-74) found Cemetery H habitation in the western portion of the high AB mound. More has been found by the American team currently working at the site. Their excavations have also produced the first radiocarbon date for the Cemetery H assemblage at 1730 cal. B.C., nicely within the expected time range.

Documentation for the Post-urban in Northern Baluchistan, the Northwest Frontier, and Derajat is also not sufficient to make comparative statements with other regions of the Mature Harappan. Moreover, these regions were not securely within the Mature Harappan cultural/political system, if style and politics can be proxied one for the other. There is a lot yet to be learned here. The University of Peshawar and a team from the United Kingdom are currently working in Bannu and Dera Ismail Khan (Rehman Dheri) which should help to overcome this deficiency.

### Summary and Concluding Statement

Table 7 is a summary of the substantive data comparing Mature Harappan and Post-urban archaeological assemblages by region.

**Table 7**: Summary of data comparing sites in different regions

| | Site Count | Average site size in ha | Settled area in ha |
|---|---|---|---|
| Sindh | | | |
| Mature Harappan | 86 | 8.0 | 688 |
| Jhukar | 6 | 5.6 | 34 |
| Cholistan | | | |
| Mature Harappan | 174 | 5.6 | 974 |
| Cemetery H | 41 | 5.1 | 209 |
| Baluchistan | | | |
| Kulli-Quetta /Harappan | 129 | 5.8 | 748 |
| Post-urban | 0 | 0 | 0 |
| Saurashtra | | | |
| Sorath Harappan | 310 | 5.4 | 1674 |
| Late Sorath Harappan | 198 | 4.3 | 815 |
| East | | | |
| Mature Harappan | 218 | 13.5 | 2943 |
| Post-urban | 853 | 3.5 | 2985 |

These figures, and the narrative developed in the body of this paper, indicate that the "eclipse of the Harappan Civilization" might hold for Sindh and Baluchistan, but in other regions, notably in the East and to a lesser degree in Gujarat, the course of culture change was different. In these areas there were strong lines of continuity through the early centuries of the second millennium, with little, if any, of the "trauma" that affected Sindh. The stark image one has for Baluchistan in the second millennium represents a clear challenge for field archaeology, because it would not seem reasonable to presume that the entire area was deserted at that time. Excavation and exploration are needed to give a more realistic sense of the culture history at that time.

The reasons behind the "eclipse" of the Harappan Civilization are still not understood, but it is clear that "eclipse" might not be the best concept with which to work. There are few sound data on which to reconstruct the environment of the northwestern regions of the Indian Subcontinent. There are some internal inconsistencies in the data sets that seem to apply to this reconstruction. Moreover, tectonic movement in this region, some on a relatively small scale, could have been a powerful force in shaping the drainage patterns of rivers, streams and lakes there during the Holocene. This observation and settlement history call into question the climatic reconstruction derived from the palynological research done on the lakes of Rajasthan.

Archaeological exploration in the Punjab, Haryana, northern Rajasthan, and western Uttar Pradesh has produced good evidence for human habitation in these areas during the opening centuries of the second millennium B.C. These are dry farming areas dependent on rainfall. The exploration records indicate a dramatic increase in habitation at this time, yet this is the period of the so-called "eclipse" of the Harappan Civilization and a period proposed to have been "arid" in this region. Lake Lunkaransar, which played a role in the "desiccation hypothesis," is c. 90 km south of the ancient Sarasvati River and therefore within, or at least on the borders of, this settlement area. The kinds of climatic changes proposed to have taken place around this body of water can be assumed to have pertained to the Punjab, Haryana, the rest of northern Rajasthan, and western Uttar Pradesh. There is an historical awkwardness here on two counts: there is a period of "eclipse" with a growth of human habitation and a proposed "aridity" at a time when archaeological data indicate widespread dry cropping.

There are other interesting things that happened at the beginning of the second millennium, to the south, in Gujarat. The story there is somewhat different from the one unfolding in the Punjab, Haryana, northern Rajasthan, and western Uttar Pradesh, but the conclusions that are emerging are similar to those reached in this paper. There is little evidence for climatic change, let alone climatic change that led to culture change. It is also clear that the history of the Harappan Civilization in Sindh and the West Punjab at the beginning of the second millennium is different from that which took place in Gujarat, especially on the peninsula of Saurashtra. There are few signs of "collapse" or "eclipse" there and at some places, such as

Rojdi, they were busy with the expansion and rebuilding of their settlements as Mohenjo-daro was being abandoned.

What is being learned about the "end of the ancient cities of the Indus" is that it was a good deal more complicated than was once thought. There is much heterogeneity in the culture history of the domains of the Harappan Civilization. What happened in Sindh and the West Punjab is not necessarily replicated elsewhere. In fact, the very thought of an "eclipse" or "end" of a civilization as the concept around which our thoughts should focus can be called into question. Although the sociocultural processes we would associate with urbanization seem to have changed drastically, life outside the urban realm is well documented as the descendants of the peoples of the Mature Harappan pursued their lives as farmers, herders, and many types of craftsmen.

There is another process that has emerged from the mapping of sites. It is readily apparent that by Post-urban times the centre of settlement was in the Punjab, Haryana, northern Rajasthan, and western Uttar Pradesh, as well as in Gujarat (Fig. 5). This is measurably to the east of the "centre of settlement" during Mature Harappan times, which should be placed in Cholistan (Fig. 4). The preceding period, the Early Harappan, is even farther west (Fig. 3), and the shift in the centre of settlement continues to move west as we trace back to the earliest settled village farming communities in the Baluchi hills and piedmont. It is not clear to me what this pattern for the location of the centre of settlement means, but it seems to be a very clear part of the archaeological record.

The question of Indus literacy is of general interest, and quite complex. The Indus script remains undeciphered (Possehl 1968c). There are significant changes in literacy that accompany the transformation process. The distinctive Indus stamp seals, both square and oblong, are no longer made after c. 1900 B.C. There is a general reduction in artifacts that were primarily intended to carry texts. Writing virtually disappears in Sindh and is at least very much reduced in the Harappa (Cemetery H) region. But, there is an abundance of graffiti in Saurashtra and northern Gujarat, as well as the Eastern Domain during Post-urban times. Characters from the Indus script even appear as graffiti on Iron Age "Megalithic" pottery in Central India, during the first millennium B.C. (Possehl 1996c: 68-75). Thus, while the Indus writing system changes, it would be incorrect to hold that it disappears with the transformation of the Mature Harappan.

Dealing with causality for the transformation of the Harappan Civilization, which is a complex, multifaceted process of change, clearly expressed in the archaeological record, is no simple matter. There are two things that deserve attention. The first was noted at Mohenjo-daro, with the abandonment of the Great Bath and Granary late in the third millennium. This may be an early expression of failure in the fabric of the city, possibly the entire civilization. Thus, whatever we see expressed in the opening of the second millennium could be the culmination of a process of urban failure that began two or three centuries earlier. The process, at least at Mohenjo-daro, was slow and gradual. The second process at work is the drying-up of the Sarasvati River. The inland delta in the vicinity of Fort Derawar might have been the Mature Harappan "bread basket," possibly a position of some importance within the overall Mature Harappan economy. There is a drop-off in settlement there as the headwaters of the Sarasvati gradually shifted from a western drainage to the east. The archaeological expression of this change in drainage is the shift between the Mature Harappan and the Cemetery H assemblages, which can be dated to the early centuries of the second millennium. But there was still enough water for the people who used the Painted Gray Ware to settle there, although possibly in much diminished numbers. How this change in the river affected the history of the Harappan Civilization is clearly complex. The most obvious thought would run to some sort of "domino effect" with the failure of the economy in Cholistan ultimately linked with changes elsewhere. Although some archaeologists find this kind of thinking attractive, it is hard to understand how the drastic changes in Baluchistan can be laid at the foot of a deterioration in the subsistence economy of Cholistan, especially when the East next door to Cholistan seems to have survived, even prospered, at the same time. The same might even be hypothesized for Saurashtra. Moreover, these models that place the explanation of cultural change in the natural world end up being excessively linear when dealing with the relationship between people and their sociocultural systems and the world around them.

There is obviously a good deal of basic archaeological research to be done on this important, fascinating problem. Several programmatic statements come to mind. There is still a need for tighter chronological control over the data that pertain to the transformation of the Harappan Civilization at the beginning of the second millennium. As noted in Table II the interface between the Cemetery H assemblage and Painted Gray Ware is still not understood. There is only one radiocarbon date for the Cemetery H assemblage. Although the Rojdi C, Lothal B period is reasonably well dated, we do not understand the interface between this assemblage and the Gujarati Early Iron Age. There are many more problems in chronology that need to be addressed.

The Jhukar assemblage in Sindh and the Cemetery H assemblage in the Punjab and Cholistan are both poorly understood. The type site seems to be stratigraphically complex (Majumdar 1934: 5-18; Mughal 1992). The other excavated site with these remains is Chanhu-daro (Mackay

1943), which is in need of reexcavation as well. Current excavations at Harappa may help to clarify some of the problems attendant on the Cemetery H material.

The successors to the Kullis in southern Baluchistan have not yet been identified. They are not the people who made Londo Ware, as was once thought (de Cardi 1951). Solving the problem of who succeeded the "Kullis" seems to be dependent on intensive, problem-oriented exploration, coupled with first test excavation at several places, followed by larger-scale excavation at the most promising site. The French research at Miri Qalat, in the Makran, might provide some information on the early second millennium peoples in their part of the Harappan world (Besenval 1992a, b, 1994; Besenval and Marquis 1993; Besenval and Sanlaville 1990).

There may be a need to increase cooperation between archaeologists and scientists interested in the ancient environment. The drying-up of the Sarasvati seems to be an important part of the second and third millennium environment. We need to know more about this in terms of chronology and to get a firmer grasp of the process as it unfolded. The same is true for the lakes of Rajasthan and Gujarat. In fact, the environment of the second and third millennia is not well-known, and clarifying this issue will have benefits that go beyond addressing the problem of understanding the transformation.

Perhaps most important, we need to rely on the fertile imagination of archaeologists interested in the transformation of the Harappan Civilization to provide a fund of hypotheses that can be tested as part of this field work. Standing alone, no amount of chronological control, exploration, and excavation is going to define the nature and reasons behind the transformation.

Even if we cannot yet fully explain the changes in the Harappan Civilization at the opening of the second millennium B.C., we do have a better grasp of the complex, diverse regional cultural histories that are very much a part of this story. We also have new observations on the Mature Harappans and their environment that might some day be shown to be clues to an expanded understanding of the emergence of the Post-urban Harappan.

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# The Prehistoric Indus River System and the Indus Civilization in Sindh

Louis Flam
Department of Anthropology
Lehman College,
The City University of NewYork
Bedford Park Boulevard
West Bronx
New York 10468-1589

## Abstract

Aerial photo composites and field research have revealed a number of post-Pleistocene fluvial remnants associated with former courses of the Indus River in the Lower Indus Valley (Sindh, Pakistan). Geomorphic and historical evidence are used to connect fluvial remnants and delineate former Indus River courses from northern Sindh to the Arabian Sea. The Sindhu Nadi is recognized as the prior course of the Indus River during the fourth and third millennia B.C. For this time period, a second perennial river, the Nara Nadi, is delineated in the eastern portion of the Lower Indus Basin, with the prehistoric coastline located in a more northerly area than that of the present day. Several implications and dynamics of ancient river course locations are suggested for the prehistoric Indus Civilization (c. 2600-1900 B.C.).

## Introduction

The study of fluvial systems in prehistory is an integral component of geoarchaeology and human palaeoecology, with an objective of linking synchronic and diachronic cultural adaptations with the dynamics of fluvial systems. Archaeological research in the Indus River Valley has documented the development of prehistoric cultures during the fourth and third millennia B.C. yet little scientific research has been conducted which specifically addresses issues concerned with the landforms and dynamic character of the Indus River in prehistory and aspects of the fluvial environment which had behavioural significance in the prehistoric past. Descriptions of the physical setting of archaeological sites and the linkages between these sites as living settlements in the past and the palaeoenvironment have been based on present-day configurations. It has been generally assumed that the location of the main channels of the Indus River and its tributaries have remained unchanged since the end of the Pleistocene. Until recently (Flam 1981, 1986a, 1993), Fairservis (1967: 24-27) had been the only archaeologist to recognize that the Indus fluvial palaeoenvironment may have been different from that of the present day, while Holmes (1968) explicitly delineated more recent, historical changes in the course of the Indus River and showed them to have been radically different from modern conditions. Furthermore, archaeological and historical studies have documented the affects Indus River course changes had on cultural developments in the Lower Indus Basin during historical times (Flam 1986b; Lambrick 1975), and this must have certainly been the case during the prehistoric period. The Indus River is presently, and has been in the near and distant past, a fluvial system of tremendous magnitude and dynamics. Toward reconstructing the palaeoenvironment of the Indus River valley and contemporary human adaptations to the dynamics of that environment in prehistory, a more explicit approach concerning the behaviour of the Indus River is necessary. The focus of the present paper is twofold: first, on presently available scientific evidence to delineate the course(s) of the Indus River during the fourth and third millennia B.C., and second, to suggest salient implications of river course locations for the prehistoric cultures of the region.

## Lower Indus Basin

The primary structural form of the Lower Indus Basin (Sindh) is a submerged geosyncline that was supplementally formed as a foredeep between the upheaval and folding of the Himalayan mountains and the stability of the Peninsular Foreland Shelf, or Deccan Shield (Baig 1969; Brinkman and Rafiq 1971; Hunting Survey Corporation 1961). Formation of this trough (Fig. 1), the Indus

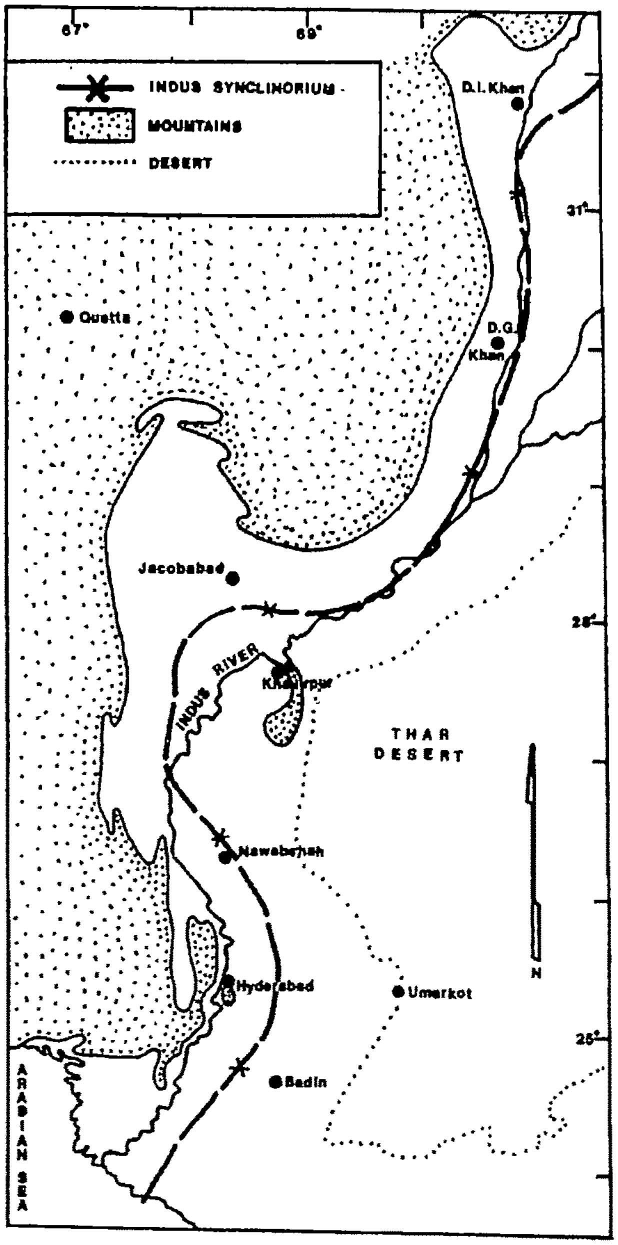

**Fig. 1**: The Indus Synclinorium (after Hunting Survey Corp 1961: Plate 8)

Synclinorium[1], began during the Mesozoic Era with processes continuing through the Tertiary Period and partially into the Pleistocene Epoch. This synclinal depression was a bay of the Mesozoic and Tertiary sea and received sediments eroded from the Himalayan landmass to the north and northwest (Brinkman and Rafiq 1971: 3). Further erosion and the removal of eroded material in the Himalaya and the Punjab filled the Lower Indus Basin with alluvium during the Pleistocene and Holocene epochs. Except for two low, isolated rock outcrops (the Rohri Hills in the northern part of the region, and the Ganjo Takar hill at Hyderabad), the landforms of the Lower Indus Basin are not the result of orogenesis or diastrophism but of Quaternary sedimentation from an aggrading fluvial system. Particularly rapid aggradation of alluvial sediments in the Lower Indus Basin began during the Early Holocene (Brinkman and Rafiq 1971: 18), with major sedimentation patterns commanded by river courses of the region. Alluvial aggradation by the rivers continued throughout the Holocene, and the lateral and vertical accretion of sediments occurred across the width of the Lower Indus basin as the rivers of the region changed their courses. Thus, the alluvial plain of Sindh was built up to an enormous depth, estimated in places to be over six hundred metres (Lower Indus Project[2] 1966: 16). To the casual observer, the river plain of the Lower Indus Basin appears to be perfectly flat, but is actually made up of subtle variations in relief which are the result of ancient and recent patterns of alluvial deposition. These alluvial deposits have distinct origins, developmental histories, and morphologies. Certainly, the fluvial processes which created these deposits have not been spatially stable throughout the geomorphological history of the Lower Indus Basin, nor in adjacent, tributary areas. Thus, it is unacceptable to assume that present-day fluvial and concomitant environmental configurations were the same five thousand years ago as they are today. Furthermore, continuing geomorphological transformations as well as human interactions with the environment throughout the Holocene have greatly altered the pristine environment which may have first attracted human settlement to the region in prehistory. The prehistoric configurations of soil, relief and hydrology, as well as potential land use would have induced considerable consequences on prehistoric populations settling in the Lower Indus Basin. It should be noted that environmental determinism is not being advocated, but a realization that when faced with varying degrees of environmental change people will make adjustments that affect their stability and, in retrospect, their developmental trajectory. This paper is concerned with environmental dynamics and cultural responses to specific geomorphic transformations. In the following discussion, evidence will be presented towards an initial reconstruction of the ancient river courses of the Lower Indus Basin during the fourth and third millennia B.C. Any discussion of the palaeogeography and palaeoenvironmental reconstruction of the region and human adaptation to prehistoric conditions necessarily focuses on the delineation of the ancient river courses of the region as a point of departure. This can only be derived from the diachronic study of fluvial processes and land forms of the region during the Holocene.

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[1] I follow Snelgrove (1967: 140) in using the name Indus Synclinorium, "to imply a broad regional syncline with superimposed minor folds, rather than a closely folded broad synclinal structure." For structural details of the syncline refer to Farah and Dejong (1979), Glennie (1956), Hunting Survey Corporation (1961), and Tainsh *et al.* (1959).

[2] "LIP" will be used throughout this paper to designate the reports of the Lower Indus Project, conducted by Hunting Technical Services and Sir M MacDonald and Partners. The Lower Indus Project report contains three parts: the "Main Report" which consists of two volumes, the "Supporting Report" which consists of twenty-eight volumes, and the "Supplements" which consist of sixty-eight volumes.

### Geology

Excluding the limestone hills near Rohri and Hyderabad, there are no physical barriers to the flow of rivers in the Lower Indus Basin. The Rohri Hills extend approximately fifty-five kilometres southward from the city of Sukkur in the northern part of Sindh Province. Another limestone hill, known as Ganjo Takar, extends approximately twenty-two kilometres southward from the city of Hyderabad in southern Sindh. Neither of these two groups of hills rises more than sixty-one metres above their surrounding plain level.

The Rohri Hills have a north-south strike with a high escarpment on their western side and a gentler slope "rarely exceeding 2°, and in many places less than 1°, to the eastward" (Blanford 1880: 102). Structurally, the Rohri Hills are not thought to be part of the Kirthar Mountains — Sindh Kohistan family, but "an independent dome isolated in a region of little or no deformation" (Hunting Survey Corporation 1961: 351). However, both Blanford (1880: 45-49, 101-108) and the Hunting Survey Corporation (1961: 85-90) have related the rocks of the Rohri Hills to those of the Kirthar Mountains and Sindh Kohistan regions. The most characteristic rock found throughout the Rohri Hills is limestone with flint. This limestone is hard and much fissured and cracked; large masses of flint in this formation make it eminently important.[3] The flint commonly weathers out and covers the surface over a large area of the hills. Other beds consist of highly fossiliferous nummulitic limestones, ironstone (near Khairpur), yellow argillaceous limestone, and pale-green clay with large quantities of gypsum, as well as occasional layers of deep-red clay.

The modern and historic city of Hyderabad sits on the Ganjo Takar hill with escapments on all sides, the southern being the highest. The rocks of the Ganjo Takar hill belong to the Kirthar Group of Sindh Kohistan (Blanford 1880: 154-155), and consist of white chalky limestone with few fossils; a formation quite unlike that of the Rohri Hills.

### Soils and Landforms

Perhaps the most important geological feature of the Lower Indus Basin is its soils. Ecologically, they play a vital role in the biotic community including, of course, potential human land use patterns. Vitally important for the analysis of ancient fluvial environments is the development of stratified alluvial deposits into distinct soil profiles and the approximate dating of these soils. Since soil development is a consequence of regional climate and vegetation, as well as edaphic conditions including type of parent material and local hydrology and topography, they may be a significant clue to past environmental conditions; that is, the soils will reflect the conditions that produced them. Therefore, a consideration of the genesis of soils (parent material), the transportation of parent material to various localities, and the transformation of parent material into distinct horizons and profiles locally and regionally, as well as their approximate age, can be a significant factor towards reconstructing the paleogeography of the primarily alluvial Lower Indus Basin.

The Soil Survey Staff (1962: 147) of the United States Department of Agriculture has summarized four major classes of soil parent material:

(1) those formed in place through the disintegration and decomposition of hard country rocks,

(2) those formed in place from soft or unconsolidated country rocks,

(3) those that have been transported from the place of their origin and redeposited either before they became subject to important modification by soil-building forces or during such processes of modification, and

(4) organic deposits.

Soil parent materials which eventually find their way into the Lower Indus Basin and form the alluvial composition of the region originally had their origin in the Himalayan landmass. In the Himalayas, the parent materials are the result of processes (1) and (2) listed above, and have been described by Drew (1873) in his classic study of the origin and forms of Himalayan alluvium. Drew noted that the general extremely cold climatic conditions of the Pleistocene Epoch brought about a great disjointing, dislocation and disintegration of rock, which then accumulated in Himalayan stream channels. The rise of temperatures and lessening frost-power during the last part of the Pleistocene brought about an increase in stream load, in erosional processes, and in denudation in the Himalayas, "both carrying down what was then being disintegrated and eating into the alluvium that had been formed" (Drew 1873: 470). This Himalayan alluvium consisted of a variety of igneous, metamorphic, and sedimentary rock material unique to the area, and was carried into the Punjab and the Lower Indus Basin by rivers with seasonally high discharges, process (3) listed above. This process created wide

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[3] The flint was a major resource for the manufacture of prehistoric stone tools (Biagi and Cremaschi 1988), and is still used today for road foundations and house bricks.

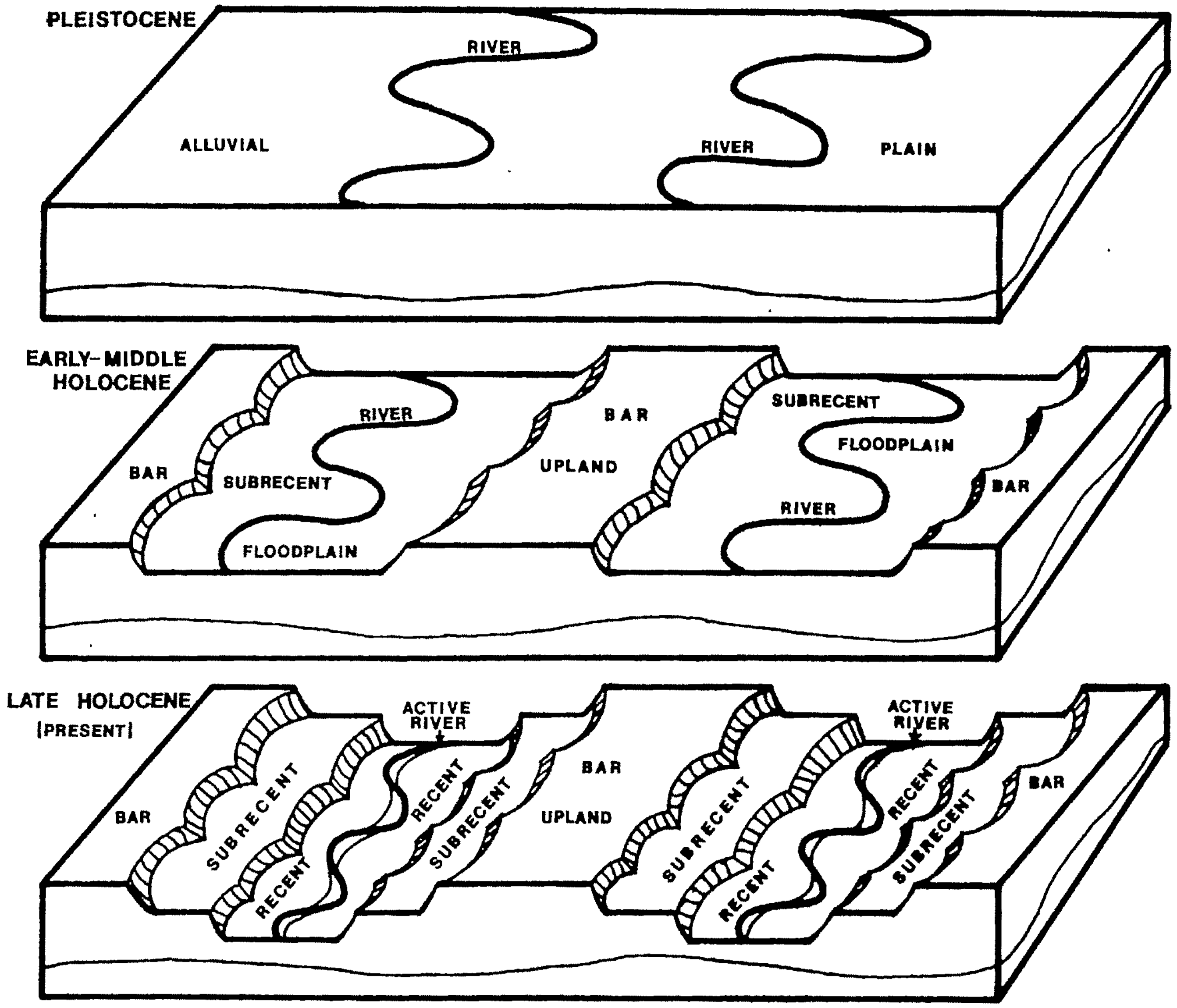

**Fig. 2**: Development of the Punjab Plains

alluvial plains in the Punjab (Fig. 2) and to a lesser extent in portions of the Lower Indus Basin. Subsequently, "during the early Holocene (Atlantic period in western Europe), wide plains were cut by the rivers of the Punjab, down-cutting in and removing the old sediments along their courses, so that steep-edged old river terraces now remain in the centre between each pair of rivers: the bar uplands" (Brinkman and Rafiq 1971: 16). This process of dissection continued through the Middle Holocene and continued into more recent times in the Punjab.[4] During the Early and Middle Holocene, eroded parent material of the Himalayan landmass as well as reworked alluvium of the Punjab plains and those of the Lower Indus Basin continued to be carried by the rivers of the Punjab and Sindh, and filled the Lower Indus Basin with alluvium. Alluvial deposition followed and was dependent on the location of ancient river courses extant at the respective time periods in the region. Once deposited the alluvium was subject to regional aspects of climate and the influence of the local biotic community. Most soils of the region show definite profile development with distinct horizons (Baig 1969: 144; LIP 1966; Rafiq 1971b).

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[4] Post-Pleistocene landforms in the Punjab have been the result of alluvial degradation. That is, the rivers of the Punjab have incised into Pleistocene land surfaces, and have deepened and narrowed their valleys (Fig. 2) In contrast to this process, the post-Pleistocene landforms of the Lower Indus Basin have been the result of alluvial aggradation, or the deposition of sediments and the building up of landforms over former surfaces.

The most important soil forming process in the Lower Indus Basin is homogenization. Brinkman (1971: 2, and Plates 1 and 2) has described this process:

> As long as temperatures are favourable (which is the case almost throughout the year in most plains areas of West Pakistan), and as long as moisture is available (from rain, run-off, river flooding or irrigation), plants grow and send their roots throughout the upper soil, and in lesser quantity throughout the subsoil. Plants die, and soil animals and micro-organisms feed on the dead roots, converting the material to humus. Pores are created either by the passage of animals or by decay of roots. Disturbance by roots and mixing by soil animals gradually destroys any stratification.

Although the degree of homogenization depends on many factors, Brinkman (1971: 2) has cited an important point which is especially relevant to the study of sedimentary environments such as the Lower Indus Basin:

> When soils have the same sedimentary and hydrological history, it is possible to estimate their relative ages from the degree and depth of homogenization.

Research conducted by Hunting Technical Services Limited and Sir M. Mac Donald and Partners under the title "Lower Indus Project" (1965a, 1965b, 1966), by the Food and Agriculture Organization of the United Nations (1971), and by the Soil Survey of Pakistan (Akhtar 1970; Akram 1971; Ali 1967, 1969; Alim 1968; Ansari 1971, 1972, 1973; Baig 1969) have used this approach to define landforms and their relative ages in the Lower Indus Basin and the Punjab. The methodology employed the use of test pits, exploratory field traverses, and the study of aerial photo composites of Pakistan (1:40,000 scale) to define and map fluvial sedimentary land form patterns.

Five land forms have been defined in the Lower Indus Basin: (1) Pleistocene remnants, (2) the Subrecent river plain, (3) Subrecent river terraces, (4) the Recent Floodplain, and (5) the Active Floodplain. During the Early and Middle Holocene "The Subrecent river plain was built up over the late Pleistocene level, due to the rise of sea level and the sediment added to the rivers by the dissection upstream" (Brinkman and Rafiq 1971: 18). In the western part of the Lower Indus Basin, the Subrecent river plain is a major land form unit comprising level plains, basins, infilled channels, and covered bars characteristic of abandoned river channels (Ansari 1973: 16). Early and Middle Holocene in date, Subrecent river terrace remnants rise about thirty centimetres to one metre above the adjoining river plain. They are further recognized in the extreme western and eastern parts of the Lower Indus Basin

> ... by their soil development to a greater depth and with a greater degree of homogenization that the soils of the main river plain...
>
> ... presumably the Subrecent river terrace is a cover floodplain deposit from the period when the Indus River followed a considerably longer, more westerly course (probably near Jacobabad). This was shallowly dissected by subsidiary Indus channels when the river found a shorter, nearer, and more easterly course. (Brinkman and Rafiq 1971: 18)

Late Holocene landforms are marked by recently abandoned river channels and levees, the Recent Floodplain, and by the present, active course of the Indus River, the Active Floodplain. The significance of these land forms for the paleogeography of the Lower Indus Basin is discussed below.

## Rivers of the Plain

The present-day course of the Indus River is located in an approximately central position in the Lower Indus Basin from Sukkur to Sehwan, and is located in the extreme western part of the region from Sehwan to the Arabian Sea. Throughout its long history the Indus has been a notably vagrant river of enormous magnitude, exhibiting extraordinary wanderings and mutations of it course in response to natural and human induced environmental changes. One major occurrence in the geomorphological history of the Indus River was the passage of the river's course through the gap in the limestone rock outcrops near Sukkur (the Sukkur gap; also known as the Bukkur gap). This "event" has been dated to a period between the tenth and thirteenth centuries A.D. (Holmes 1968: 379; Lambrick 1967: 489-490; LIP 1965a — Volume 2 — Appendix V: 15), and has ever since remained the fixed course of the Indus River. Referring to Arab texts of the relevant time period (Lambrick 1975: 181-184), Holmes noted that "the full flow of the river was probably passing through the Sukkur gap by 1252 A.D. and certainly by 1333, by which time it was flowing on both sides of the Bukkur island" (Holmes 1968: 379). The repercussions of this event were enormous throughout the Lower Indus Basin. In relation to previous courses this new one through the Sukkur gap exhibited greater sinuosity, a wider meander plain, enlarged channel dimensions, and patterns of increased alluvial deposition (Holmes 1968: 377-381; LIP 1965a — Volume 2 — Appendix V: 15-16). Implicit in these changes are characteristic increases of regimen including sediment load, rates of discharge, and river gradient changes.[5] The reasons for these changes and the resultant change in the river's course are not well understood but recent research has been undertaken to address these issues (Jorgensen *et al.* 1993; Schumm 1985, 1986).

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[5] For an explanation of the mechanics of rivers see Allen (1965), Leopold and Wolman (1957) and Schumm (1968, 1971b, 1972a, 1977, 1986)

The present-day course of the Indus River in Sindh is held in location by flood protection embankments (*bund*) on either side of the river along its entire length. These embankments exaggerate the buildup of alluvial sediments along clearly and narrowly delineated parameters, raising the bed of the river unnaturally above its floodplain as well as preventing any major change in the river's course.[6] The natural morphology of the river has been further modified by the attempted control of the Indus River's perennial and ephemeral tributaries in the Punjab and western piedmont areas of the Northwest Frontier Province, respectively. In addition to the Indus River's protective embankments in the alluvial area of Sindh, a protective *bund* separates the river plain from the seasonal torrent streams of the Kirthar Mountains and western piedmont region. The hydrological regulation of the Indus drainage net[7] by barrages and large scale irrigation canals has reduced peak discharges, prolonged periods of water flow, and trapped alluvial sediments, "virtually putting an end to the natural flooding activity [of the river], the canals replacing the [natural] flood channels and field irrigation replacing the natural covering activity [of the river]" (Memon 1969: 6). Consequently, the man-induced alterations of sediment load, regime, and runoff reception have greatly altered Indus River morphology (see Schumm 1971a, 1971b for similar situations), and have created an "artificial landform" (Memon 1969: 15) of the Indus floodplain. The point to be made is that the present-day course and concurrent landforms of the Indus floodplain are *recent* phenomena. It is erroneous to assume that the ancient courses of the present day Indus River and factors influencing the fluvial environment of the Lower Indus Basin in prehistory were similar to those of the present day. Although recent reports (e.g. Fraser 1958; Revelle 1964) are significant contributions to the study of the present-day Indus River, its landforms, and land use patterns, a note of caution should be struck in their uncritical application to the prehistoric situation.

In order to trace the course of the Indus River during the fourth and third millennia B.C. it is necessary to approach the fluvial environment of the Lower Indus Basin in historical perspective. This entails the establishment of a chronological sequence of fluvial events in the region and a consideration of how the geomorphic environment evolved to its present configuration.

The scientific methods and theory for the study of ancient sedimentary environments is becoming more sophisticated and precise (Middleton 1965; Pettijohn 1962; Rigby and Hamblin 1972; Schumm 1968, 1972a, 1977; Selley 1978). However, the criteria for the reconstruction of palaeochannel shape and dimensions, as well as the precise causal relationships of fluvial changes are lacking for the fluvial deposits of the Lower Indus Basin. Therefore, any effort to study the chronological sequence of former river courses in Sindh remains largely descriptive. The accuracy of the descriptive nature of these sequences is greatly enhanced by the use of historical, geomorphological, and aerial photographic evidence to trace and date former river courses in the Lower Indus Basin.

Previous attempts to delineate river courses in the Lower Indus Basin have used historical sources (Greek, Roman, and Arab geographies, histories, or travel accounts), sometimes coupled with ground observations to describe fluvial remnants. In addition, evidence and inferences from historical sources and ground observations in the light of geomorphic processes has added a new dimension to the study of Lower Indus Basin fluvial history (Lambrick 1975). In the majority of previous studies, linear patterns of soil types and the distribution of micro-relief landforms were attributed to variations in the present-day course of the Indus River. While attempting to trace ancient river courses, researchers oftentimes mistakenly attributed small spillway channels, sometimes of recent date, as the historical remnants of major stream channels or river courses. The regional significance of soil and landform patterns was oftentimes misunderstood and misinterpreted.

The most accurate and detailed evidence concerning the ancient fluvial environment of the Lower Indus Basin has come from the combined use of historical source material, theory and field data concerning the fluvial geomorphology of the Lower Indus Basin, and most important, the use of aerial photographic interpretation correlated with field studies (Holmes 1968; LIP 1965a — Volume 2 — Appendix V). Soil and landform patterns not readily visible or traceable for distances from ground surveys are easily delineated and related to each other from aerial photographs. The arid climate of Sindh and the lateral shifting of the Indus' courses over the wide plain of the Lower Indus Basin have preserved old river channels and their landforms. Although portions of older river course reaches have disappeared or have been damaged by younger fluvial activity, or human cultivation, enough remnants of older courses remain to permit the delineation of entire river courses. "The evidence of the photographs cannot be disputed, and the old river courses can be traced with absolute certainty" (LIP 1965a — Volume 2 —

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[6] One example of the *bund* system in Sindh is the Begari Bund Located on the right bank of the Indus River northwest of Sukkur, this *bund* directs the Indus toward the Sukkur Gap and prevents the river from adopting a westerly course from Kandhkot Without the *bund*, the river would adopt a course almost exactly similar to the Warah Course discussed herein (Fig 5) During severe flooding of the Indus River in 1976 and 1977, the Begari Bund was breached and the river adopted the Warah Course as just noted

[7] "A drainage net is the arrangement of streams within the drainage basin" (Allen 1965: 93), and are of two types: contributive (add their discharges), and distributive

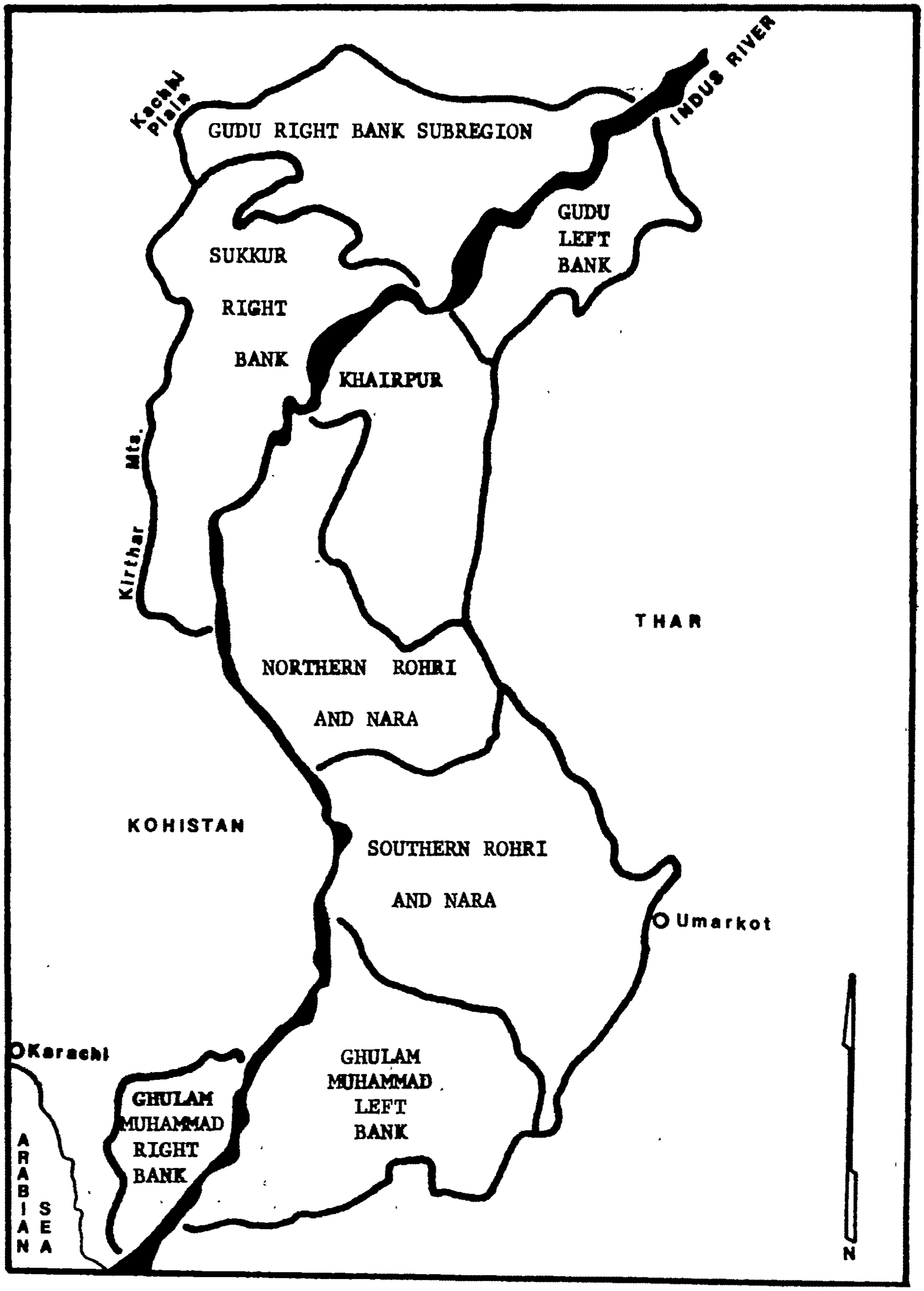

Fig. 3: Subregional location map for figures 4-11

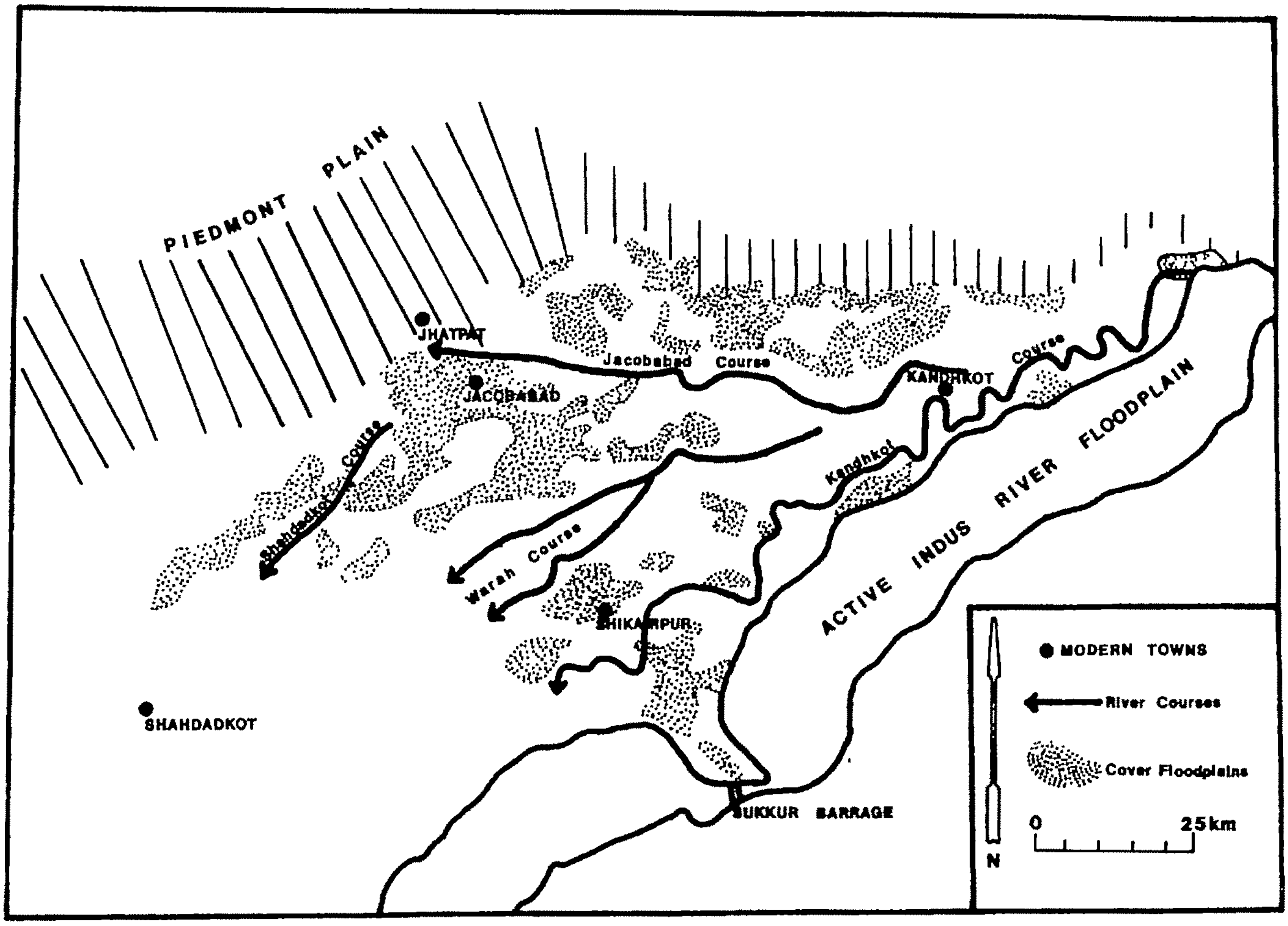

**Fig. 4**: Gudu Right Bank Subregion (after LIP 1965a — Volume 2: Figure 6.3)

Appendix V: 2). In the light of the evidence from aerial photographs and recent field studies, Lambrick's (1975) reconstruction of the ancient fluvial environment of the Lower Indus Basin exhibits the greatest degree of accuracy. Although not completely accurate and not detailed with regard to the fourth and third millennia B.C. time period, Lambrick's analysis did lay the foundation for further studies, such as the present one.

Using the combined evidence from historical sources, aerial photo composite interpretation, and field research, Holmes (1968) and the Lower Indus Project (1965a — Volume 2) have delineated six major post-Pleistocene river course remnants in the northwest and north central alluvial plain subregions of the Lower Indus Basin (Fig. 4, 5, 7 and 8):[8]

1. Jacobabad Course
2. Shahdadkot Course
3. Warah Course
4. Kandhkot Course
5. Khairpur Course
6. Present day course of the Indus River

In the southern subregion of the Lower Indus Basin four major post-Pleistocene river course remnants have been delineated (Fig. 8-10):

7. Sanghar Course
8. Samaro-Dhoro Badahri Course
9. Shahdadpur Course
10. Present day course of the Indus River (with distributaries)

In the northeastern, central-eastern, and southeastern subregions of the Lower Indus Basin another series of course remnants have been delineated (Fig. 6-10):

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[8] For continuity, I have generally adopted the names given the various river courses of the Lower Indus Basin by Holmes (1968) and the Lower Indus Project (1965a, 1965b, 1966). The present study partially digresses from this nomenclature when delineating the river courses during the fourth and third millennia B.C.

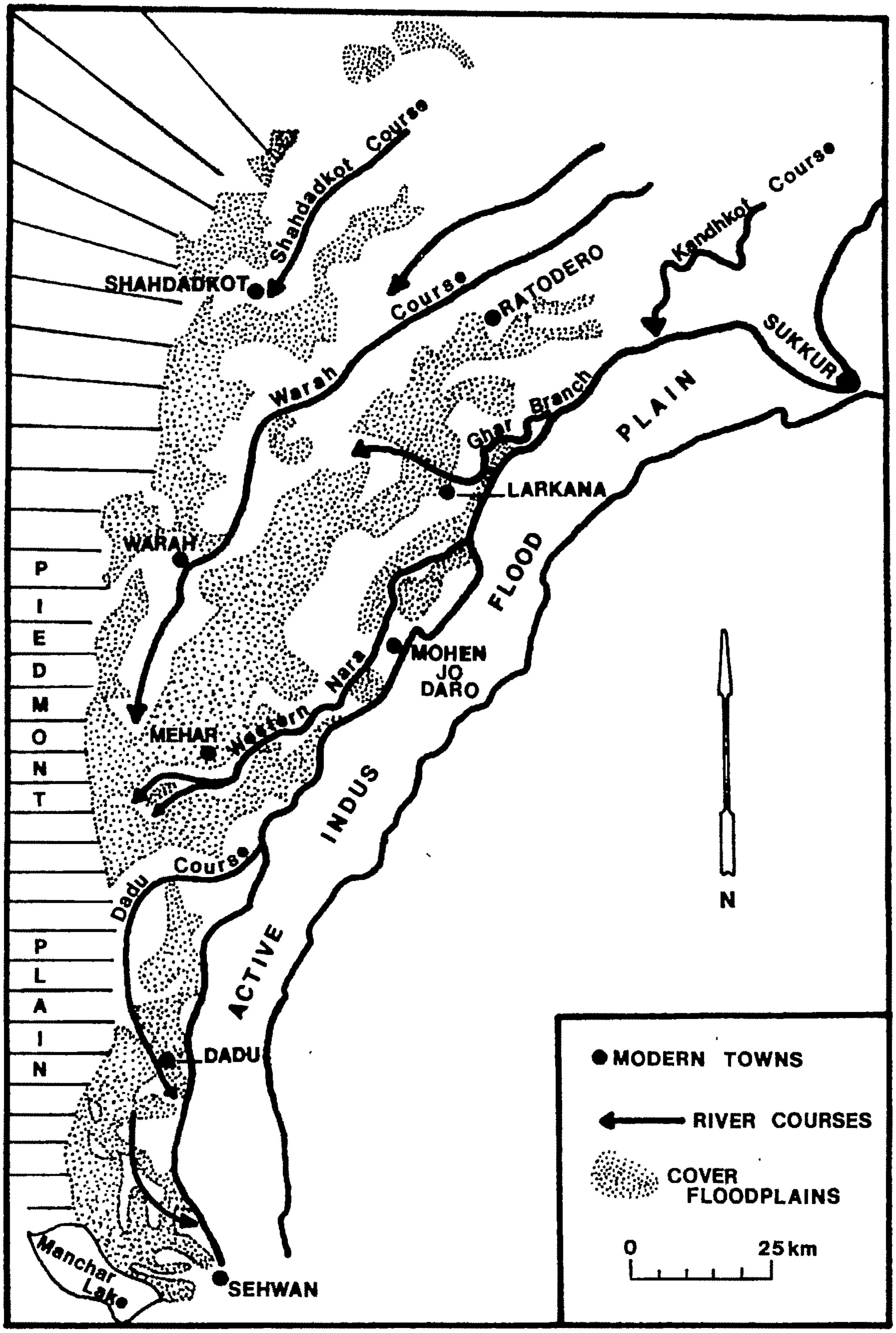

Fig. 5. Sukkur Right Bank Subregion (after LIP 1965a — Volume 2: Figure 6.4)

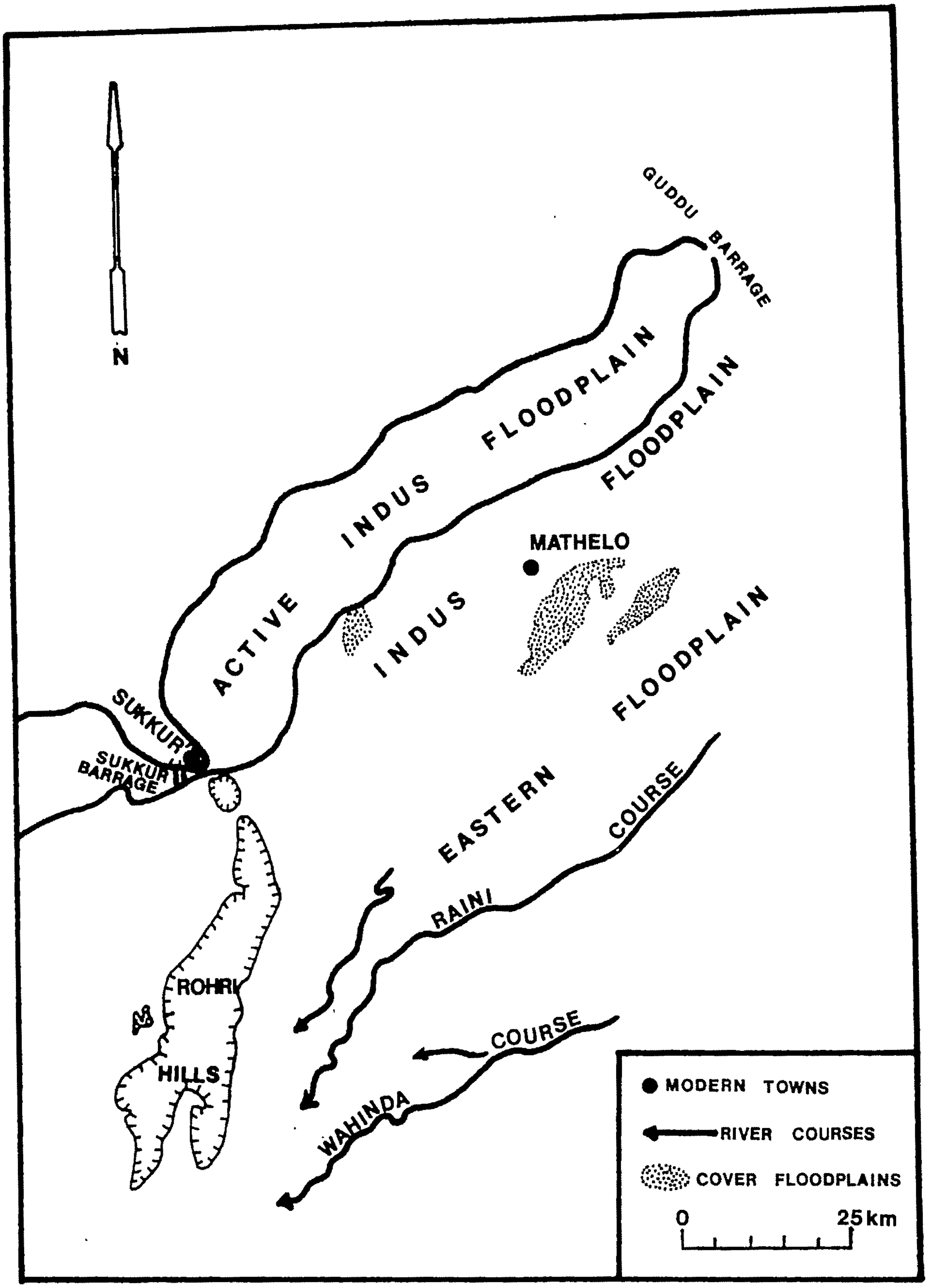

**Fig. 6**: Gudu̥ Left Bank Subregion (after LIP 1965a — Volume 2: Figure 6.2)

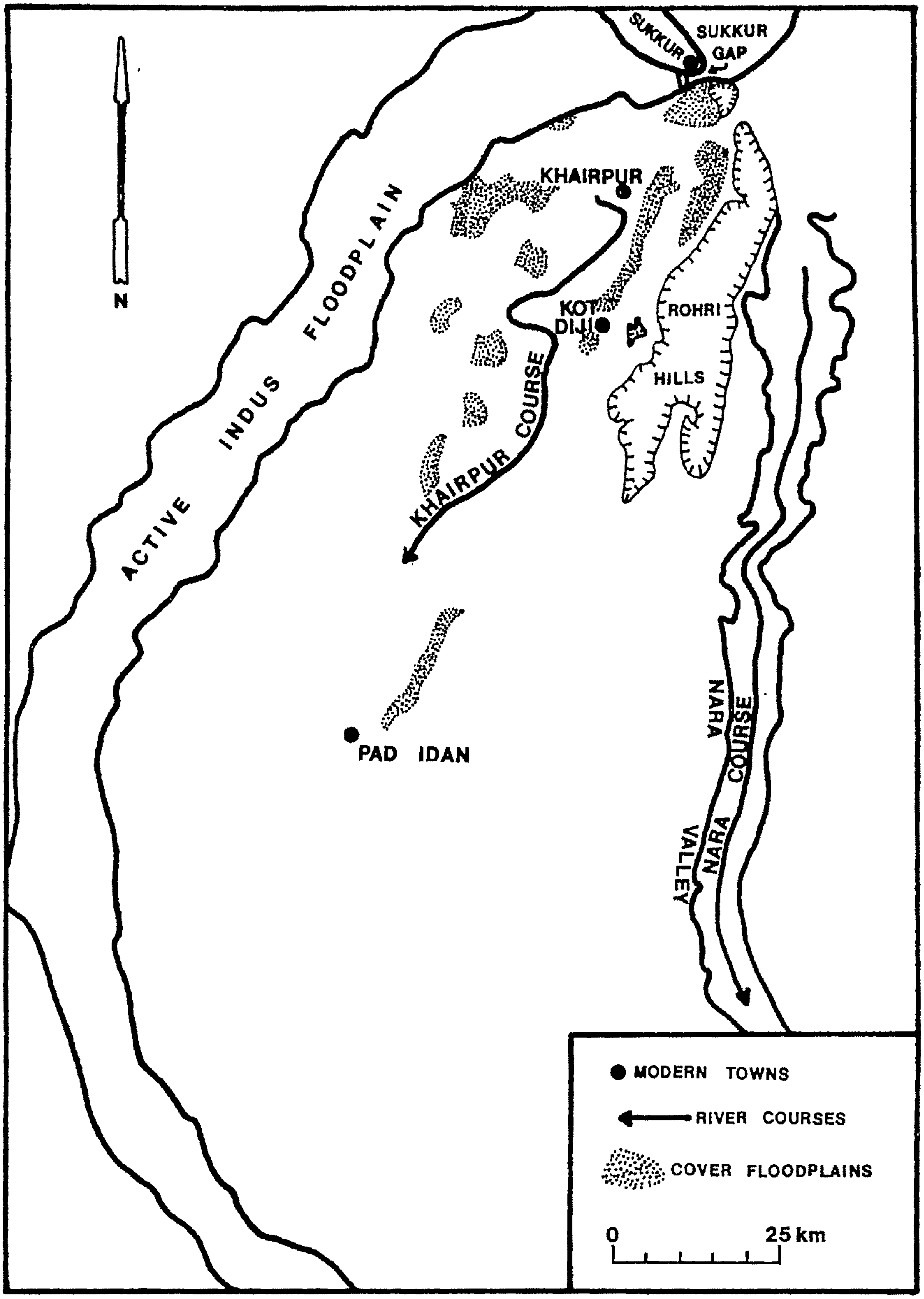

**Fig. 7**: Khairpur Subregion (after LIP 1965a — Volume 2: Figure 6.5)

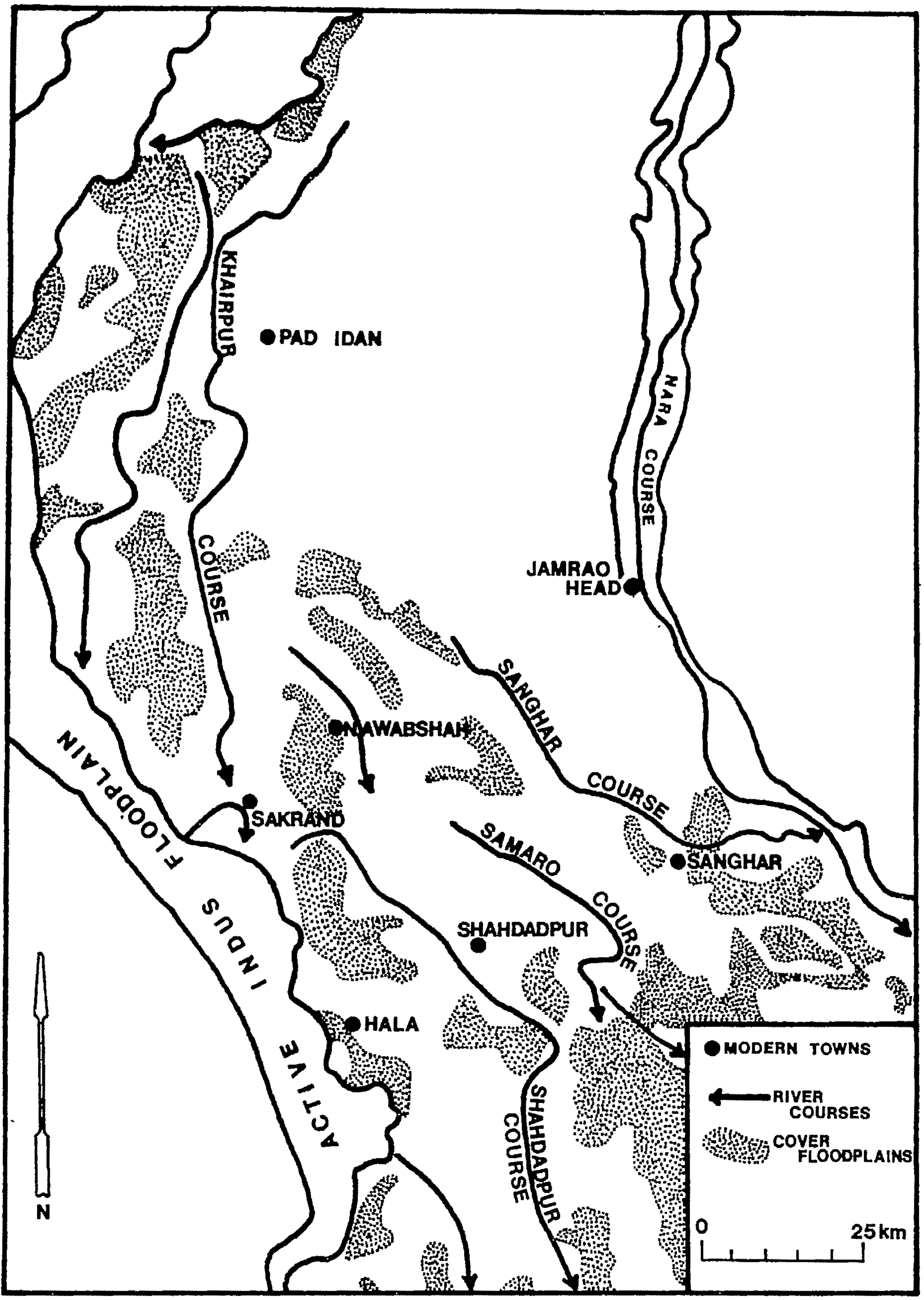

Fig. 8: Northern Rohri and Nara Subregion (after LIP 1965a — Volume 2: Figure 6.7)

11. Wahinda Course
12. Raini Course
13. Nara Course

Of the course remnants listed above, numbers one through ten belong to former or recent courses of the Indus River, while those numbered eleven through thirteen belong to the distinct, and exclusive Nara River system. Following Butler (1950), Pels (1964), and Schumm (1968), the Jacobabad, Shahdadkot, Warah, Sanghar, and Samaro-Dhoro Badahri course remnants can be considered "prior stream" courses of the present-day Indus River, and the Kandhkot, Khairpur, and Shahdadpur course remnants can be considered "ancestral" courses of the present-day Indus River. The **prior** stream channels comprise the oldest sets of courses, while the **ancestral** channels mark the younger courses of the Indus River before it adopted its present-day course.

### *Jacobabad and Shahdadkot Course*

The Jacobabad Course (Fig. 4), marked by Subrecent river terraces, is traceable as the most northwesterly and oldest of the former river remnants in the Lower Indus Basin. Traces of this course emerge from the present-day Indus River near Kandhkot and run in a westerly direction toward the town of Jacobabad (from which the course derives its name). In the vicinity of Jacobabad the course's remnant deposits become mixed with Kachi Plain piedmont sediments and thereby become untraceable a short distance west of Jacobabad town.

Another course remnant is "traceable as a zone of bars and channels from southwest of Jacobabad down to Shahdadkot" (Holmes 1968: 371). This remnant, the Shahdadkot Course (Fig. 4 and 5), disappears south of Shahdadkot town. It is possible that this course is the remnant of a distinct and independent river course; that is, separate from the Jacobabad Course. However, aerial photo composites of the area, as well as maps of the prior river courses of the Lower Indus Basin permit the speculation that the Jacobabad and Shahdadkot channels were two reaches of one and the same river. There are no other traceable remnants north and west of the Shahdadkot Course except the Jacobabad Course, and the two appear aligned at their respective ends southwest of Jacobabad town. Farther south of the Jacobabad-Shahdadkot Course, northwest of Warah town, Holmes (1968: 371) discerned an additional river course remnant (not named by him) in the area now occupied by Hamal Lake. Holmes concluded that this latter channel "shows the characteristic crescentic channel and bar patterns of Indus meander flood plains, and it is believed to be a continuation of the Jacobabad Course (or possibly the Shahdadkot Course), obscured in the intervening portions by piedmont alluvium of later date." Putting the pieces together, the Jacobabad, Shahdadkot, and "Hamal Lake" remnants constitute a single, ancient course of the Indus River. Holmes concluded, and the present study concurs that, "There is thus evidence of a distinct river system running around the northwestern flank of the Indus alluvial plain, south to Manchar Lake, now partly obscured by the advance of the piedmont alluvial plain" (Holmes 1968: 371).

### *Warah Course*

Another channel, the Warah Course (Fig. 4 and 5) can be recognized as a distinctive "broad zone of extensive high bar deposits and clearly defined channels" (Holmes 1968: 371); its deposits are indicative of a major river. Similar to the Jacobabad Course, the Warah Course had its origin near Kandhkot. Unlike the Jacobabad Course, which ran due west from Kandhkot, the Warah Course turned toward the southwest a short distance west of Kandhkot. Running southwest of Kandhkot, the Warah Course is clearly traceable as it passes west of Shikarpur and Ratodero, through Warah, and west of Mehar towns. In the area west of Mehar the alluvial deposits of the Warah Course are intermixed with Kirthar Mountains piedmont plain deposits, the latter often obscuring the former (Ansari 1973: 14; Bull 1972). The intermixing of Kirthar piedmont plain alluvial deposits and alluvium of the Warah Course occurs along the entire length of a trough which extends from Jacobabad to Manchar Lake. As noted above, the deposits of both the Jacobabad and Warah courses blend into this trough. Previously, this trough was thought to have been a major independent river course of the westernmost part of the Lower Indus Basin (Fraser 1958; Memon 1969; Pithawala 1936, 1959), but this is not precisely the case.[9] It was a major river course in that it was an extension and part of the Jacobabad and Warah courses. Holmes and the Lower Indus Project have not assigned a specific name to this western trough. Raverty (1895: 310) called it the "Sind Hollow".[10] This designation has been used by Panhwar (1969), and will be followed in the present paper.

### *Kandhkot Course, Khairpur Course, and Shahdadpur Course*

Another former river traceable in the northwestern part of the Lower Indus Basin is the Kandhkot Course (Fig. 4 and 5). This course is "for most of its length a single channel, narrow, deep, and winding, running parallel to the modern

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[9] This trough has been named the Western Nara channel by Fraser (1958), Memon (1969), and Pithawala (1936, 1943, 1959), and should not be confused with the seasonal spillway of a later time period named by Holmes (1968 371-372) the "Western Nara" (see Fig. 5).

[10] Raverty (1895. 310) noted that the western trough of the Lower Indus Basin was variously referred to locally as "the Ran, or Marsh, the Pat, or desert, the Dasht-i-Bedari," and the Sindh Hollow.

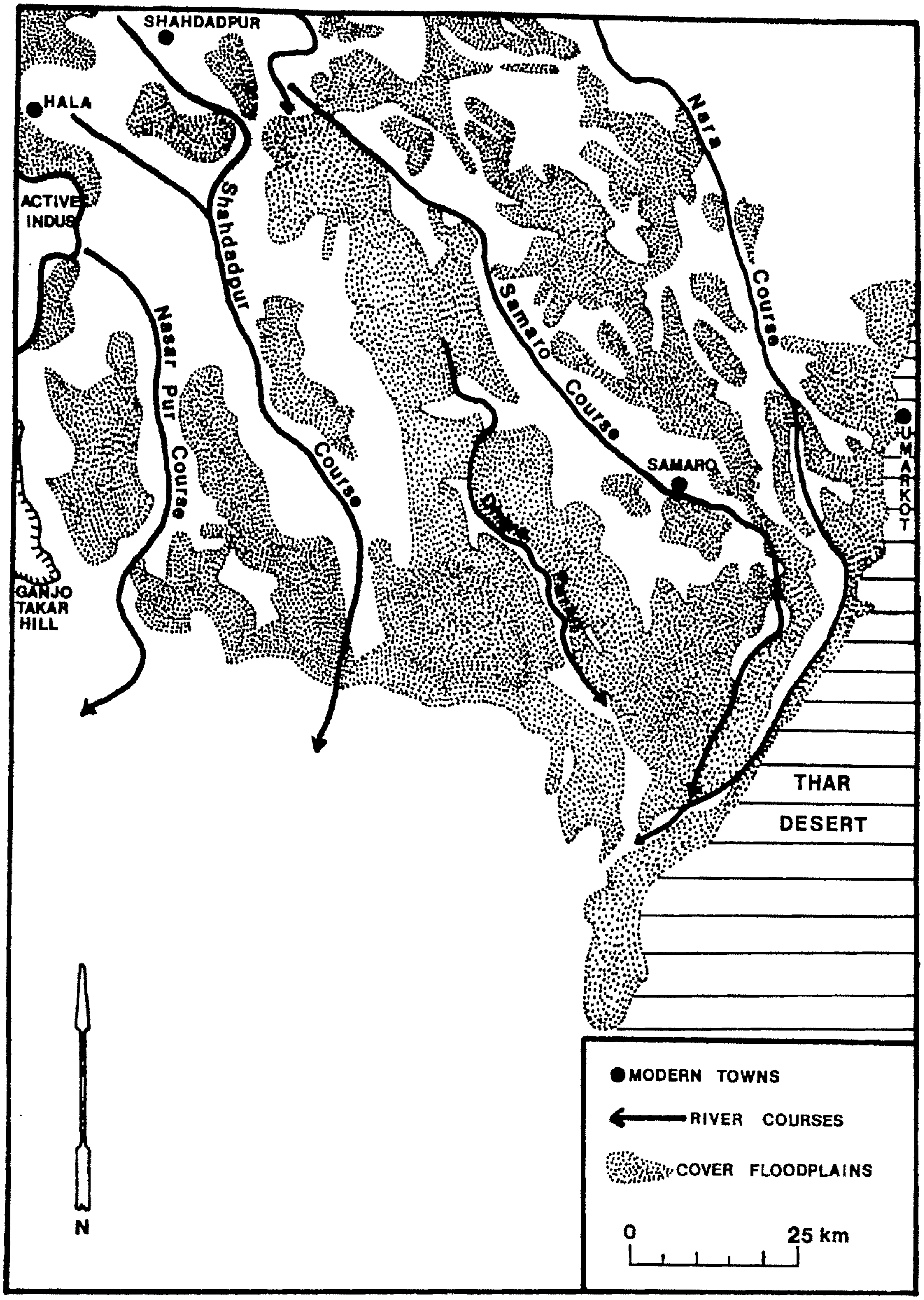

**Fig. 9**: Southern Rohri and Nara Subregion (after LIP 1965a — Volume 2: Figure 6 8)

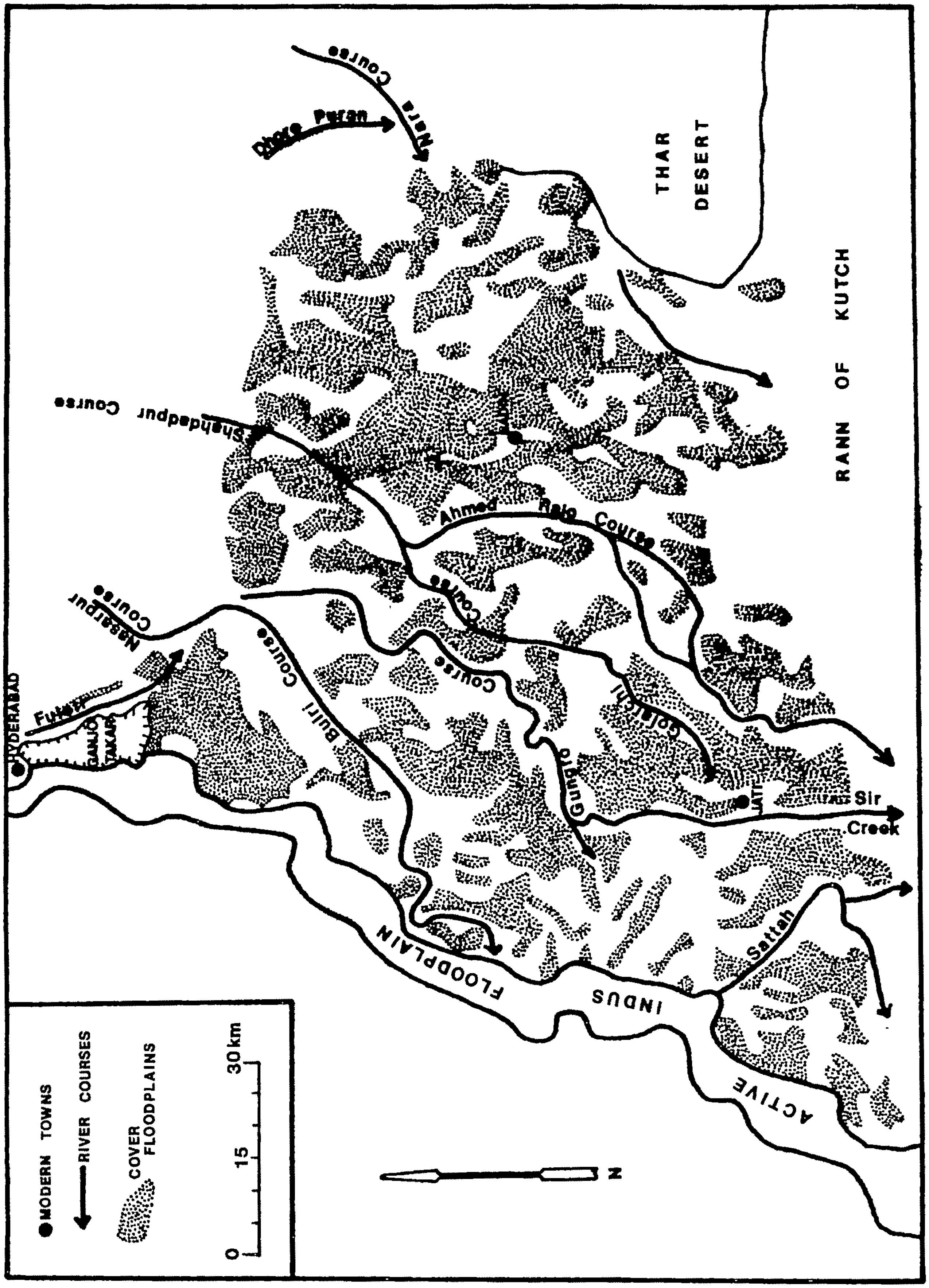

Fig. 10· Ghulam Mohammad Left Bank Subregion (after LIP 1965a — Volume 2: Figure 6.9)

Indus river from Kashmore, through Kandhkot which is located on its bank, to south of Shikarpur, where it is cut by the modern Indus" (Holmes 1968: 371). The morphology of this channel suggests that it was a large river, the previous (ancestral) course of the present-day Indus River before it flowed through the Sukkur gap (LIP 1965a — Volume 2: 406). Two spill channels are traceable on the aerial photo composites as offshoots of the Kandhkot Course and the more recent Indus River: the Western Nara Course and the Dadu Course (Fig. 5). Holmes has pointed out that neither channel has ever been a major branch of the Indus River, as had been proposed by some earlier writers, and that in fact the dates of these distributaries are relatively recent (Holmes 1968: 372).

The Kandhkot Course, on the right bank of the present-day Indus River, is complemented on the left bank of the modern river by the older Khairpur Course (Fig. 7 and 8). The Khairpur Course can be traced from west of Khairpur city, southward to Sakrand. A short distance south of Sakrand begins the Shahdadpur Course (Fig. 8-10) of the southern Indus plain. Holmes (1968: 372- 374) has reasoned that the Kandhkot, Khairpur, and Shahdadpur courses were reaches of the same river, based on their similarity of channel form: "narrow, deep channels, meandering with a tighter radius than the modern river, between high sandy bar deposits" (Holmes 1968: 373).

### *Sanghar Course and Samaro-Dhoro Badahri Course*

In addition to the Shahdadpur Course, two other unconnected remnants in the southern portion of the Lower Indus Basin are traceable on the aerial photo composites: the Sanghar Course and the Samaro-Dhoro Badahri Course (Fig. 8 and 9). These two courses are of special interest in that neither channel was part of the Kandhkot-Khairpur-Shahdadpur river, nor were they part of the Eastern Nara Course (see below); but they may be a clue to the seaward path of the Jacobabad and Warah courses.

The Sanghar Course is discernible about twenty kilometres northwest of Nawabshah, where it follows a southeasterly course to Sanghar town. From Sanghar the course runs eastward and joins the channel of the Nara Course. Holmes noted that the Sanghar channel is narrow and appears to have been a stable river which, by all available evidence, carried the heavy floodwaters of a major river branch, or possibly a major distributary.

The Samaro Course's remnants originate approximately twenty kilometres southeast of Nawabshah and continue in a southeasterly direction through Samaro town. Continuing past Samaro, the course joins the Nara Course via the Dhoro Badahri channel.

The remaining courses of the southern and southwestern portions of the Lower Indus Basin (Fig. 9-11) which have been described by Holmes and the Lower Indus Project are pertinent to the later Arab and Muslim periods, and are beyond the scope of the present paper (see Flam 1986b). These courses were distributaries of the ancestral and present-day courses of the Indus River.

### A Chronology of Rivers

Thus far the discussion of the former courses of the Indus River in Sindh has focussed on the recognition of various fluvial remnants derived from aerial photo composite interpretation and ground observations. Toward reconstructing the fourth and third millennia B.C. course of the Indus River it is a logical next step to connect the various course remnants, trace entire lengths of former rivers from northern Sindh to the Arabian Sea, and suggest dates for the activity of the various rivers.

The present day course of the Indus River is, of course, the easiest to define and date. As noted above, the course of the river through the Sukkur gap, and its associated landforms, are less than one thousand years old. Therefore, it is unlikely that the prehistoric river can be equated with the present-day course.

Looking back in time, the river marked by the Kandhkot, Khairpur, and Shahdadpur courses[11] is the second river that can be documented, and by historical sources as well. Lambrick (1975: 100-132) has used the writings of Greek and Roman geographers and chroniclers (Arrian, Megasthenes, Strabo, and Pliny) to locate and date this early course of the Indus River in Sindh. He presented the following points which aid in locating the Greek period river. First, the reporters of Alexander's river journey through Sindh make no mention of the Indus' course through the limestone hills in the Sukkur, Bukkur Island, Rohri vicinity, a unique occurrence which they would have taken special note of while en route through Sindh. Lambrick (1975: 108) suggested that the river must have flowed either west or east around the Rohri Hills, if it did not pass through them as the present day river does (i.e. through the Sukkur gap). Aerial photo composites show that a spill channel of the Indus flowed to the east of Rohri at some time, but its dimensions are not large enough to indicate that the main river *ever* flowed in this channel (Holmes 1968: 372; LIP 1965a — Appendix V: 3). Lambrick inferred that the Greek period course of the Indus River did not flow too far west from Sukkur. This flow can now be confirmed by the location of the Kandhkot Course (Fig. 4 and 5). Second, Lambrick (1975: 112, 192) maintains that during the Greek period the Indus

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[11] The Kandhkot-Khairpur-Shahdadpur Course will hereafter be referred to as the Kandhkot Course. It should be noted that prior to A.D. 1758, the Indus River flowed approximately twenty-four kilometres east of its present day course west of the Ganjo Takar hill (Holmes 1968: 381; Lambrick 1975, LIP 1966: 17)

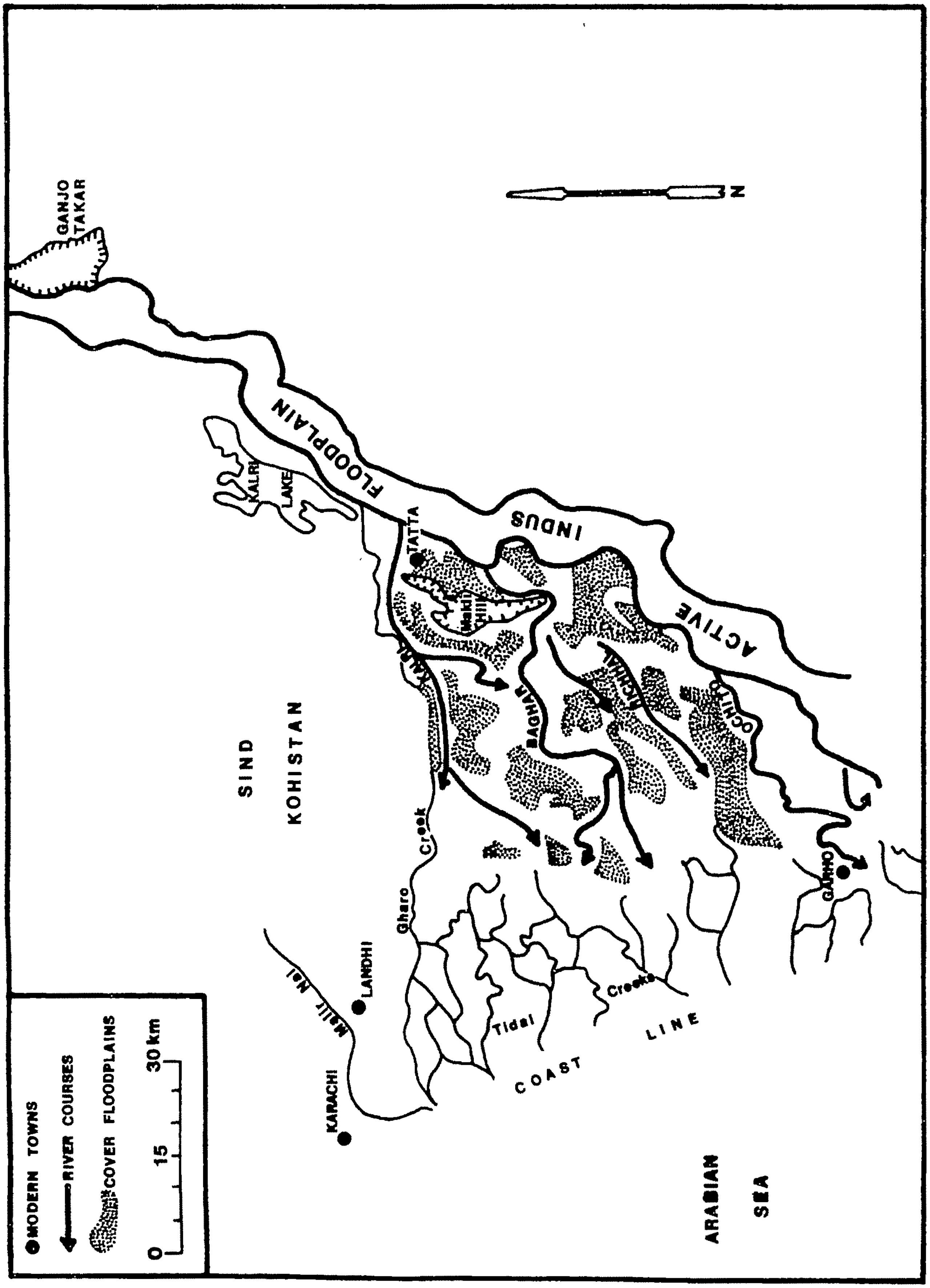

Fig. 11: Ghulam Mohammad Right Bank Subregion (after LIP 1965a — Volume 2: Figure 6.10)

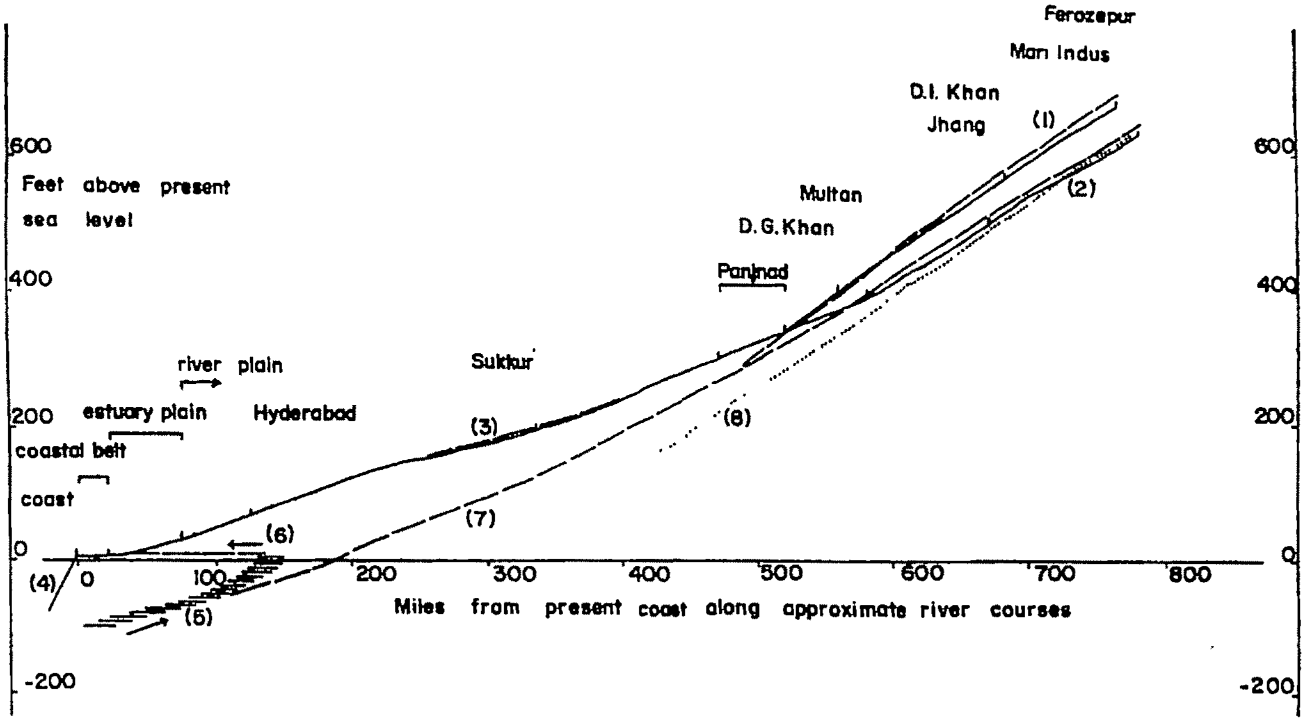

**Fig. 12**: Schematic Longitudinal Section of the Indus Plains (from Brinkman and Rafiq 1971: 17)

**Legends**: 1: Solid line: Indus river floodplain. Dashed line: approximate surface of Thal.
2: Solid line: Chenab and Sutlej floodplains Dashed line: Old river terrace, silty cover. Dotted line: Old river terrace, sandy base.
3: Solid line: Indus river floodplain. Dashed line: Subrecent river terrace.
4: Submarine slope
5: Presumed movement of coastal belt until about 6,000 years before present.
6: Presumed movement of coastal belt during last 6,000 years.
7: Presumed buried surface of Old river terrace silty cover.
8: Presumed buried surface of Old river terrace sandy base.

flowed east of the present-day city of Hyderabad and the Ganjo Takar hill. This also is confirmed from the aerial photo composites and the geomorphic evidence of the subregion (Holmes 1968: 381; LIP 1966: 17), and is marked by the Shahdadpur Course (Fig. 8-10). Third, without the aid of aerial photographs, Lambrick's map (1975: Map 3), "Sind in 326-325 B.C.," illustrates his hypothesized path of the Indus River during the Greek period. This proposed course matches almost exactly and is confirmed by the Kandhkot Course mapped from the aerial photo composites.[12]

While historical evidence suggests an approximate date for the adoption of the Indus River's present-day course, as well as the period of activity for the Kandhkot Course, the date for the adoption of the Kandhkot Course, and the dates for the activity of the Jacobabad and Warah courses are not aided by historical evidence. For these latter details it is necessary to turn to the approach provided by theoretical fluvial geomorphology, and the geomorphological and sedimentological history of the Indus drainage system.

Two concepts from fluvial geomorphology are especially relevant in the present context. One has been stated by Schumm (1972b: 1; see also Mackin 1948; Strahler 1950): although short reaches of a river can and should be studied, "it is always well to remember that the channel is a component of a bigger and more complex system, the drainage basin." In the present context this means that although the Lower Indus Basin is the region at the centre of this study, events in this region cannot be separated from the entire system of the Indus River and its tributaries from their headwaters in the Himalayas to the delta near the Arabian Sea.

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[12] With the Kandhkot Course defined as the Greek period location of the Indus River, some question may arise as to the configurations of the islands Prasiane (in northern Sindh) and Patale (in southern Sindh). Megasthenes (Fragment LVI, in Pliny, Hist. Nat. VI, 23) stated that the Indus divided Sindh into these two islands. In this context it is important to note that Alexander the Great travelled through Sindh during the late summer of 325 B.C (Lambrick 1975: 107). The Kandhkot Course, therefore, would have been at flood stage It seems valid to suppose that, just as in the present-day (see Footnote 6, above), the Warah functioned as an overspill channel after it was abandoned as the main channel of the river Thus, Prasiane would have been formed of the western Indus floodplain. In the south, Patale would have been formed by the main river and flood flow in a major distributary channel, perhaps marked by the Samaro-Dhoro Badahri Course.

Another concept in fluvial geomorphology which is worthy of special attention is that of the "graded stream," which has been defined by Mackin (1948: 471). While a graded river system may never occur in nature, the concept is vital to an understanding of fluvial geomorphology and river adjustments to altered hydrologic regimen (affecting discharge, sediment load, channel dimensions, and gradient), to changes in gradient due to tectonics, diastrophism or a raise in sea level, or changes in the type of sediment load moved through the system (see Schumm 1965, 1968, 1969, 1977, 1986; Schumm and Lichty 1965). A river system will adjust appropriate sections of its length in response to changes in any of the above named factors, which will similarly trigger changes in other sections of the river in a "domino effect."

For the following analysis the Indus drainage basin will be divided into four major sections: (1) the northern headwaters which are located in the high altitude, mountainous regions of the Karakorams and the Himalayas; (2) the subjacent Punjab plains; (3) the Lower Indus Basin; (4) the Indus delta. It is well to remember that the following brief evolutionary history of the Indus drainage system lacks processual details and precision due to the paucity of field data. This has been somewhat alleviated by the work of the Lower Indus Project and subsequent studies by the Soil Survey of Pakistan. The evolutionary sequence of landforms for the Indus system has been clearly presented in abbreviated, table format by Brinkman and Rafiq (1971: Table 1). Farah and DeJong (1979) and Shroder (1993) present an up-to date documentation and interpretation of the geology and geomorphological processes in Pakistan.

During the Mesozoic Era and Tertiary Period, the Punjab plains and the Lower Indus Basin were a bay of the Arabian Sea. Strong folding and uplift in the mountains to the north and west (extending into the Quaternary) increased gradients in the drainage system. To adjust to this sharp disequilibrium, the drainage system deposited large amounts of sediment derived from the mountains into the bay in an effort to lessen the gradient. The pattern of sedimentation during the Mesozoic Era and Tertiary Period, as well as during the greater portion of the Pleistocene epoch, proceeded from northwest to southeast. During the last glacial phase of the Pleistocene, deposition of sediments and processes of soil formation proceeded rapidly in the northern regions. Dissection and removal of sediments in the uplands brought about rapid deposition along the shallow, strongly seasonal Indus and eastern rivers (of the Punjab). In the Punjab, deposition of mainly sandy sediments and windblown loess occurred during the main part of the last glacial phase of the Pleistocene (as a time frame). During the late part of the last glacial phase, sandy and loess deposits of the main glacial phase were covered by silty alluvial sediments. Extensive soil formation and development continued during this last phase. Thus were formed the extensive river plains of the Punjab (Fig. 2), as well as partial alluvial plains of the Lower Indus Basin.

Post-Pleistocene environmental adjustments in the Indus drainage system were a response to the hypsithermal interval of the Early and Middle Holocene epochs. These were the essential periods of alluvial deposition in the Lower Indus Basin which produced the surficial landforms of the riverine plain, which are the focus of the present study. Brinkman and Rafiq (1971: 18 and Table 1) have described the following salient features of the Early Holocene environment of the Indus drainage system: (1) the climate was warmer and more humid than that of the present-day. The effect of temperature and precipitation on runoff and river discharge have been discussed by Schumm (1965, 1968, 1969). Climate will also affect vegetal cover in the catchment of a drainage basin, thereby exercising an influence on runoff, "which in turn, will modify the sediment yields and concentrations" (Schumm 1965: 785). For the Indus system, the Early Holocene climate translated into less erosion in the regions of the headwaters and larger, more constant river flows with less sediment load. An increase in discharge probably resulted in an increase in sediment size carried by the rivers; (2) the Pleistocene river plains in the Punjab were dissected (incised) by channel erosion toward a new equilibrium grade, beginning the process of river terracing and the creation of interfluves, or bar uplands (Fig. 2); (3) the post-glacial climate brought about a rise in sea level to present levels. In the Lower Indus Basin the coastline moved northward to a location between Hyderabad and Sukkur; (4) due to dissection upstream (attempting to adjust gradients in the north) and the rise in sea level (effectively increasing the gradient in the south), there was rapid aggradation of sediments in the Lower Indus Basin. To adjust its gradient, sediment accretion was greatest near the coast. Thus, down cutting in the Indus system was greatest in the north and northeast, decreasing southward to near Multan where it was virtually nonexistent; accretion was greatest in the south and southeast, decreasing northward to near Multan where it was virtually nonexistent. This relationship and subsequent cycles are clearly illustrated in Figure 12.

During the Middle Holocene the relative magnitude of changes in climate were enough to alter the hydrologic regimen of the rivers in the Indus drainage system. Brinkman and Rafiq (1971: 18 and Table 1) have noted the following environmental conditions for the Middle Holocene in Pakistan: (1) the climate was similar to that of the present-day, with less rainfall than during the Early Holocene. The decrease in rainfall caused a removal of vegetation and an increase in erosion in the northern and northeastern uplands. Hypsithermal climatic adjustments resulted in greater seasonal runoffs with higher flood peaks and shorter duration of flood flow — the prevailing conditions of the present-day Indus River. Increased erosion lessened river gradients. Due to the nature and cycle of runoff, sediment loads probably shifted from sands to silty-clays, and can be expected to have seasonally varied from low to high suspended load concentrations; (2) lateral erosion and terracing continued in the river plains of the Punjab, but more locally limited than in the previous phase; (3) sea level remained constant. However, the estuary plain and the coastline of the Lower Indus Basin began a relatively rapid movement southward due to delta building. Thus, the river plain encroached over the former estuary plain; (4) in the Lower Indus Basin proper, aggradation continued, but was more dependent on seasonal cycles and was less rapid than in the previous phase. Soil formation (homogenization) was interrupted where local flooding and accretion were occurring.

The infilling of the Lower Indus Basin with alluvial sediments has been the primary factor of landform development from the Pleistocene to the present day. For the most part, Pleistocene landforms have been buried by later geomorphic processes (interestingly, the prehistoric site of Mohenjo-Daro is located on a Pleistocene high); where these landforms do occur they do not generally form patterns which might be traced as Pleistocene river courses. Therefore, the determinable history of fluvial landforms and river courses in the Lower Indus Basin begins with the Early Holocene and continues to the present day.

In the northwestern subregion of the Lower Indus Basin the oldest fluvial remnant has also been determined to be the most northwestern in location, the Jacobabad Course (Holmes 1968: 371; LIP 1965a — Volume 2: 406). The Sanghar Course and the Samaro-Dhoro Badahri Course are the two oldest remnants in the southern subregion; a pre-Greek period date for their activity has been inferred (Holmes 1968: 373). The Sanghar Course is the older of the two deposits, and exhibits "all the characteristics of an infilled deltaic distributary, as encountered in Lower Sind" (Holmes 1968: 373).

The environmental characteristics of the Early Holocene provides some aid in securing a date for the Jacobabad-Sanghar Course. It has been suggested that the Early Holocene coastline of the Lower Indus Basin was located north of Hyderabad city. Of the two oldest remnants in the southern subregion of the Lower Indus Basin the Samaro-Dhoro Badahri Course would have been under the sea during most of the Early Holocene. The hydrologic regimen, gradient, and type of sediment load which has been indicated for the Early Holocene can be favourably compared to the channel characteristics of the Jacobabad, Shahdadkot, and Sanghar courses. That is, the broad zone of bar and channel deposits, the coarse-textured (sand) sediment load, and the adjustments to grade of the "Jacobabad Course" correlate well with the hydrologic regimen, sediment type, and gradient descriptions of the Early Holocene phase in the Indus drainage system. On this basis, and on the relative dating from the degree of homogenization of soils (personal communication: Soil Survey of Pakistan), the activity of the Jacobabad River can be estimated to have been during the early Holocene (c. 10,000-6000 B.P., or about 8000-4000 B.C.). However, the precise dates for the respective adoption and abandonment of this course by the river are unknown.

Schumm (1965, 1968, 1969, and 1977) has demonstrated that changes in hydrologic regimen are reflected in changes in channel morphology (width-depth ratio, sinuosity, and gradient) and sediment load. Such a change in hydrologic regimen has been suggested to have taken place during the transition from the Early to the Middle Holocene in the Indus valley. The transformations that took place would have brought changes in channel stability, changes in river course, and changes in channel morphology. The Warah Course, in the northwestern subregion of the Lower Indus Basin,

> ... is more distinct than the Shahdadkot Course, recognized above Ratodero as a broad zone of extensive high bar deposits and clearly defined channels. Below Ratodero, relief is more subdued, and evidence is restricted to a few ox-bow swamps, and the deep channel of Drigh Lake west of Qambar, but below Warah the course is temporarily well-defined again, before disappearing completely in the trough sediments of the Sind Hollow (Holmes 1968: 371).

The Lower Indus Project report (1965 — Volume 2: 406) further characterizes the Warah Course as larger, more prominent, and more recent than the Jacobabad Course. In the northeastern subregion of the Lower Indus Basin, the Samaro-Dhoro Badahri Course is compatible with the supposed Middle Holocene advancement of the riverine plain by delta building. As the delta encroached southward it increased the length of the river and reduced the river's gradient. To maintain its gradient vis-à-vis its amount and type of sediment load (silty-clay) and discharge (seasonal highs and lows), the river can be expected to have increased its sinuosity and channel dimensions. When compared to the Jacobabad Course, these conditions are those hypothesized for the Warah Course. The river descriptions for the Warah Course are in accord with the environmental conditions described for the Indus drainage system during the Middle Holocene. In addition, if the Warah Course is more recent than the Jacobabad Course yet older than the Kandhkot Course, it is temporally and spatially correct to place the Warah Course "between" the latter two. Thus, a Middle Holocene date (c. 6000 B.P., or 4000 B.C.) is assigned to the activity of the Warah, Sindh Hollow, and Dhoro-Badahri courses. Furthermore, I suggest that these were reaches of a single river during the greater part of the fourth and third millennia B.C. and that this river be named the Sindhu Nadi, thereby emphasizing its prehistoric, regional integrity and distinction.

While river adjustments from the Jacobabad Course to the Sindhu Nadi can be attributed to relative changes in hydrologic regimen as a consequence of respective Early and Middle Holocene environmental changes, the question of the river's transformation from the Sindhu Nadi to the Kandhkot Course is more enigmatic. For the Middle and Late Holocene, major environmental changes such as those noted for the transition from the Early to the Middle Holocene do not appear to have been a factor. The Middle and Late Holocene environmental conditions continued to be similar. To what cause, and at what time period is it possible to attribute the change in the main river course from the Sindhu Nadi to the Kandhkot Course? Recent research (Jorgensen *et al.* 1993) has provided data to suggest that tectonic disturbance of Indus Valley slope in northern Sindh was responsible for this river course change, and may have contributed to the shift from the Jacobabad Course to the Sindhu Nadi as well. The Kandhkot Course has been characterized as a single, narrow, deep, and winding channel. This description is very different from that for the Sindhu Nadi, a broad zone of extensive deposits with a higher degree of sinuosity than the Jacobabad Course but less than the Kandhkot Course. The change of river course from the Sindhu Nadi to the Kandhkot Course seems to be an equal or greater change in magnitude than that between the Jacobabad and Sindhu rivers. With the latter two, the southern reaches adapted to the temporal growth of the delta and the upper reaches (Jacobabad and Warah remnants) adjusted their courses to altered hydrologic regimen. The middle reaches of these two rivers remained the same: the Sindh Hollow. In all sections of its length the location of the Kandhkot Course differs from the path followed by the Sindhu Nadi. With the change in course, the delta shifted from an eastern to a central location in the Lower Indus Basin. Concurrently, the central and upper reaches shifted from a western to a central location. These transformations suggest a change in hydrologic regimen commensurate with the capture of the Ghaggar-Hakra River by the Gangetic system and the change in the Sutlej River and its catchment area to becoming a tributary of the Indus system (see below, Nara Nadi). The Sutlej River has the highest average annual discharge of all the main Indus tributaries of the Punjab as they exit their mountain catchments and enter the plains (Ali 1971: 12):

| | |
|---|---|
| Sutlej | 33,318 $m^3$ |
| Chenab | 32,084 $m^3$ |
| Jhelum | 28,382 $m^3$ |
| Ravi | 7,404 $m^3$ |

An increase in water and sediment discharge of that magnitude would have had dramatic effects downstream in the Lower Indus Basin, including changes in Indus River's paleohydrology (long term discharge of water and sediment), flow characteristics (depth, velocity, turbulence), and channel morphology (width, depth, slope, shape, pattern) (see Schumm and Lichty 1965, and Jorgensen *et al.* 1993). Archaeological evidence from Cholistan (Mughal 1993) confirms critical cultural changes occurring at the end of the third millennium B.C. as the process of river capture began and the Ghaggar-Hakra River discharge began to flow into the Gangetic system and the Hakra bed began to dry up. In the Lower Indus Basin, as the river shifted its course from the Sindhu Nadi to the Kandhkot Course, prehistoric settlements which formerly had been at a safe distance from severe seasonal river flooding were being inundated every year during the flood season. The settlement's new proximity to the meander floodplain of the Kandhkot Course would have made their existence tenuous.

To review, three former courses of the present-day Indus River have been delineated in the Lower Indus Basin for the time period from approximately 8000 B.C. to A.D. 1300. The earliest river, Early Holocene activity, has been named the Jacobabad Course (Fig. 13) and was comprised of the Jacobabad, Shahdadkot, Sindh Hollow, and Sanghar course remnants of the Lower Indus Basin. A second river, later in date (Middle Holocene activity) than the Jacobabad Course, has been named the Sindhu Nadi (Fig. 14), and was comprised of the Warah, Sindh Hollow, and Samaro-Dhoro Badahri course remnants of the Lower Indus Basin. A still later river (more recent) has been named the Kandhkot Course (Fig. 15) and consisted of the Kandhkot, Khairpur, and Shahdadpur course remnants of the Lower Indus Basin. The most recent course is that of the present day Indus River (Fig. 16). This can be summarized as follows:

Prior courses of the Indus River in Sindh:

1. Jacobabad Course (Early Holocene); Figure 13:

   Jacobabad, Shahdadkot, Sindh Hollow, and Sanghar remnants.

2. Sindhu Nadi (Middle Holocene); Figure 14:

   Warah, Sindh Hollow, Samaro-Dhoro Badahri remnants.

Ancestral course of the Indus River in Sindh:

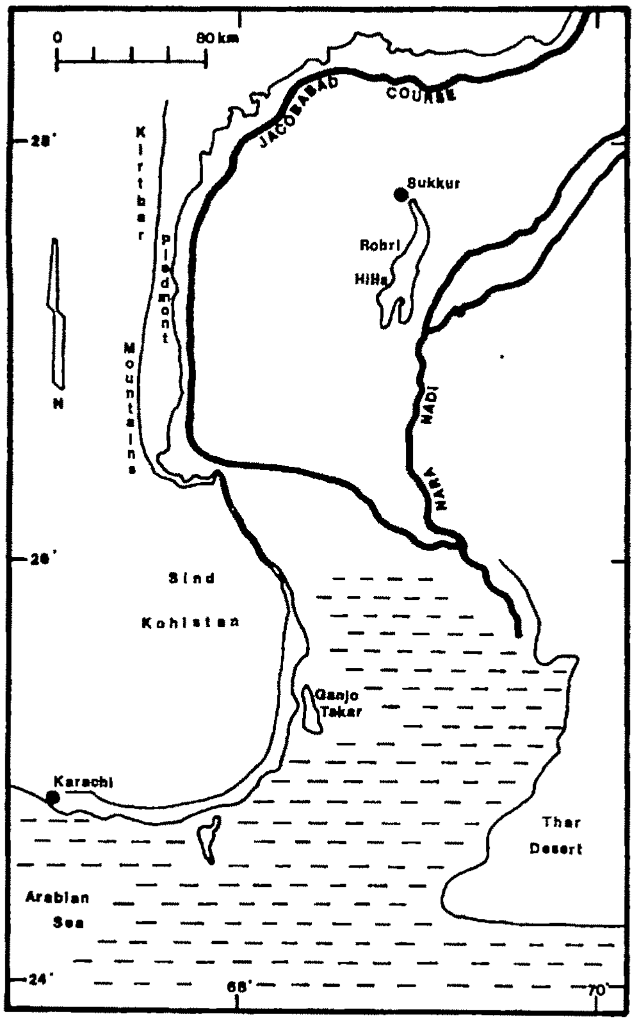

**Fig. 13**: The Jacobabad Course

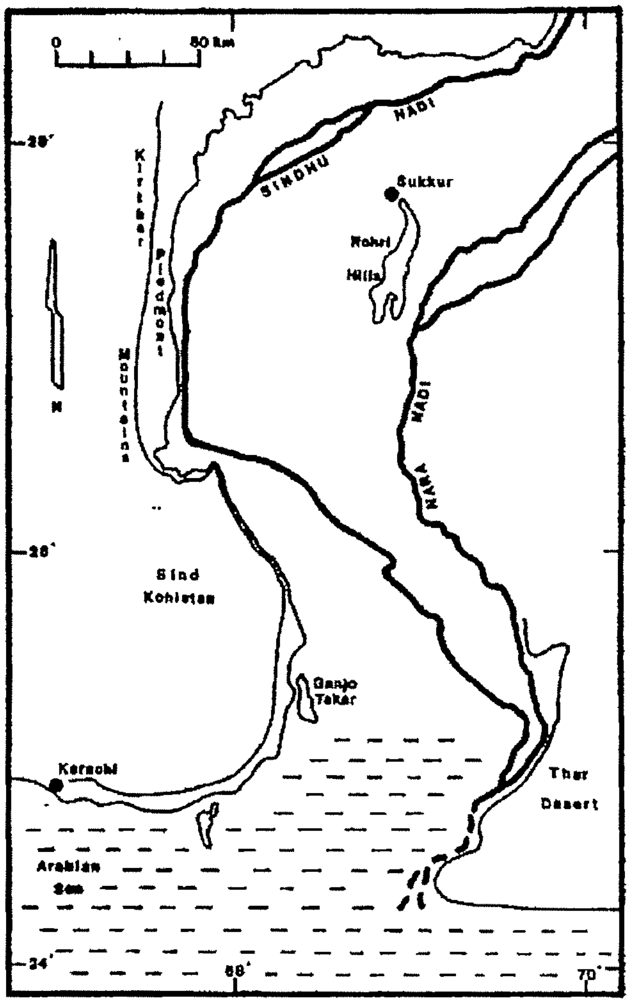

**Fig. 14**: The Sindhu Nadi and Nara Nadi

3. Kandhkot Course (Middle-Late Holocene); Figure 15:

   Kandhkot, Khairpur, Shahdadpur remnants.

   Recent course of the Indus River in Sindh:

4. The present-day course of the Indus River with deltaic distributaries

   (c. post- A.D. 1300 to modern); Figure 16.

It is very important to emphasize that these courses represent the **main** channels of the respective rivers. These configurations do not account for spill channels and inland and deltaic distributaries which may have functioned as part of the system at any given time, especially in years of extraordinary floods. In addition, it should be noted that during the activity of the prior and ancestral courses there were no controls on the natural flooding of the river, a condition which would have likely promoted flow divergence to spill channels and distributaries, as well as playing an important locational role in main channel avulsion.

### Nara Nadi

In the extreme eastern portion of the Lower Indus Basin a separate river system from the Indus and its former courses is recognizable on the aerial photo composites of the region. This eastern river, the Nara Nadi (Fig. 7-10), has been known by various names throughout its length in Pakistan. In its northeastern-most reaches from Fort Abbas to Fort Derawar it is known as the Hakra River (Mughal 1981, 1993). From Fort Derawar to the area southeasf of the Rohri Hills the course is marked by the Raini and Wahinda remnants (Fig. 4). From the area southeast of the Rohri Hills to the Rann of Kachchh the course is known as the Nara Nadi. This latter part of the Nara's ancient, natural channel has been excavated in modern times to become a feeder canal of the present-day irrigation system of Sindh Province. Thus, at least a part of the ancient course has been preserved from the vicissitudes of encroaching sand dunes from the Thar Desert.

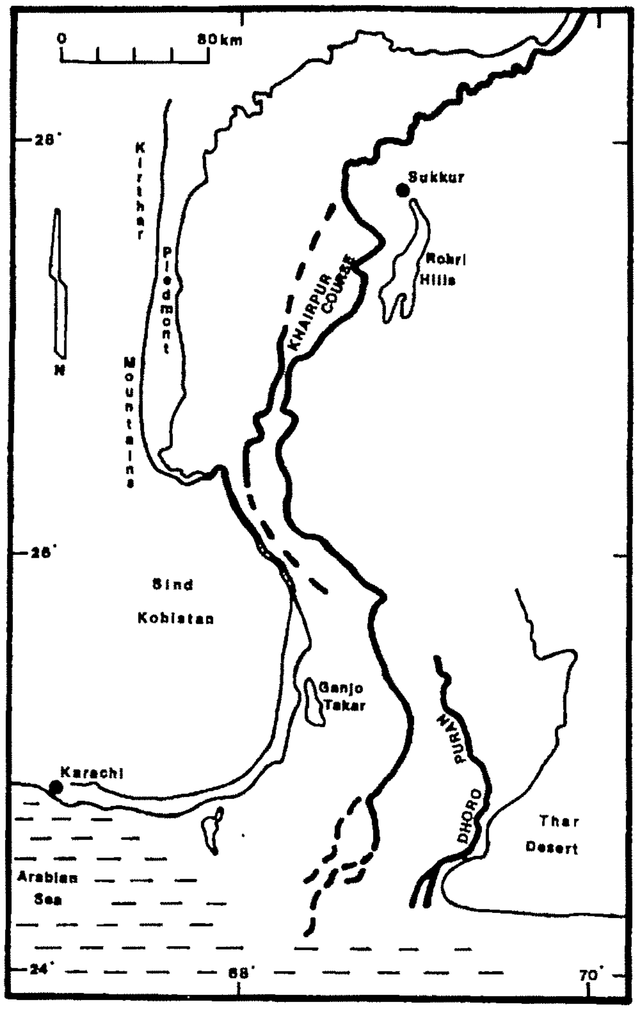

**Fig. 15:** The Kandhkot Course

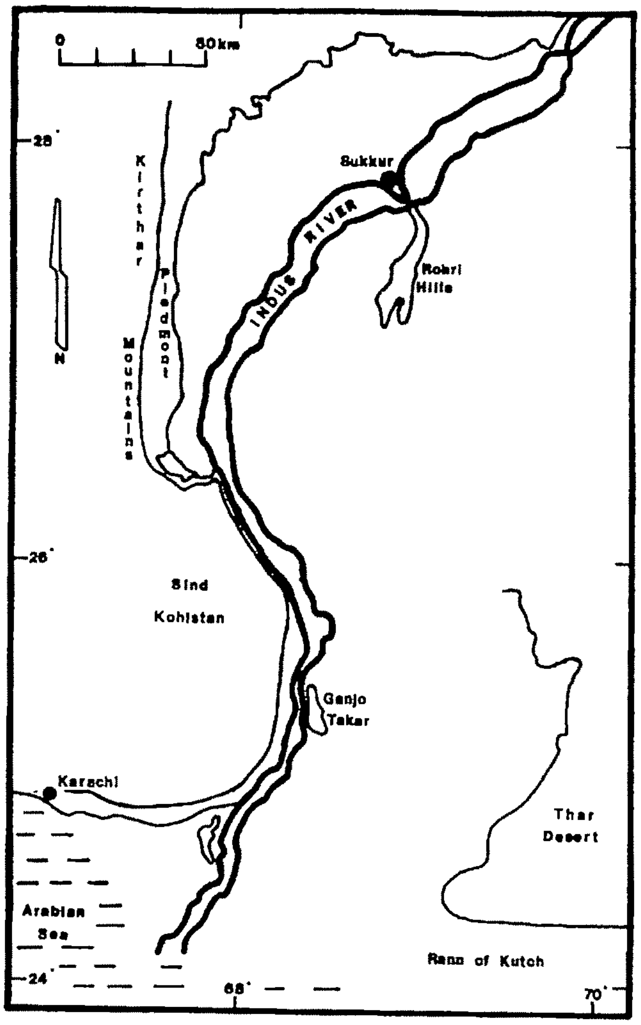

**Fig. 16:** The Present Day Course of the Indus River

The role of the ancient Nara Nadi and its northern reaches (Hakra, Raini and Wahinda) have long held the interest of geographers, geologists, geomorphologists, and archaeologists with regard to the hydrography and evolution of drainage systems of the Indus and Ganga rivers. Two early writers, Pascoe (1919) and Pilgrim (1919), speculated about the possible existence of one great river system along the entire submontane region of the northern and northeastern Himalayan landmass which drained into the Arabian Sea. Pursuing research on this river system independently, Pilgrim named the river the Siwalik, while Pascoe named it the Indo-Brahm. This river was supposed to have carried the combined discharge of the Indus, Ganga and Brahmaputra rivers. Pascoe thought the Indo-Brahm existed until the end of the Tertiary Period, when, river by river, proceeding west to east, the Indus drainage system captured the Jhelum, Chenab, Ravi, and Beas affluents. During this cycle of events the Sutlej and the Yamuna rivers began to flow westward from the Himalayas into an independent Ghaggar-Hakra-Nara course, and the Ganga became another independent river system. Thus Pleistocene tectonics dismembered what was a single expansive river system and evolved into three exclusive systems: (1) the Indus, (2) the Ghaggar-Hakra-Nara, and (3) the Ganga. Pascoe noted that the last occurrence in this cycle of geomorphic "events" was the capture of the Sutlej River by the Indus system and the concomitant capture of the Yamuna River by the Ganga system. This last series of events precipitated the drying-up of the Ghaggar-Hakra-Nara course. It should be noted that river capture and the drying of the captured stream are not single event phenomena occurring over a short period of time. The captured river will continue to flow for an indefinite time period, but in its shrunken condition its morphological characteristics will change due to a lessened volume of water and alluvium carried in the channel; it thus becomes a "misfit" stream (Lobeck 1939: 198-199). The Ghaggar-Hakra-Nara was a highly seasonal stream, as were and are the Indus and its tributaries. Changes in the flow characteristics of the river would have had a slow and continuing impact on human settlement in the region, and this is indicated in the archaeological record (Mughal 1993). It is not presently known if the Sutlej and the Yamuna were captured at the same time or different times, and if at different times how much time passed between the two "events." There is little doubt and little disagreement that the Hakra-Nara Nadi was a seasonal river with perennial characteristics during the fourth and third millennia B.C. (Akram 1971; Allchin *et al.* 1978; Ansari 1971; Holmes 1968; Lambrick 1975; LIP 1965a — Appendix V; Wilhelmy 1969).

The Hakra Course from Fort Abbas to Fort Derawar is marked by a depression which is clearly visible on the aerial photo composites. The depression has been partially filled-in by sheet floods and local erosion since the Hakra lost its discharge. Akram (1971) has defined five fluvial landforms for the Bahawalpur area, two of which are pertinent to the Hakra's floodplain. The landforms are indicative of a long history of deposition by an active river. One landform has been designated "old rolling sand plains," which are undulating sandy ridges of Late Pleistocene date. Another landform is the "Subrecent Floodplain," which lie elevated above the Recent Floodplain of the Hakra, and is Early to Middle Holocene in date (Akram 1971: 8).

Southwest of Fort Derawar, east of Rahimyar Khan, the Hakra Course becomes increasingly unclear and intermittently becomes "lost" beneath the sand dunes which have encroached upon the area. Remnants of the Hakra's course reemerge where dunes are less numerous. From Fort Derawar to the south, the Hakra can be aligned with the Raini and Wahinda remnants, which subsequently connect with and blend into the Nara channel.

The aerial photographs show the Raini and Wahinda area to have been one of great alluvial deposition. Two quite separate cycles of fluvial deposition are apparent, one associated with the Indus River, and another associated with the Hakra-Nara Nadi (LIP 1965a — Volume 2: 399, 429). The slope and contours of this area fall from the northwest to the south-southeast, with the Nara course occupying the lowest contour line along the eastern edge of the Lower Indus Basin. This sharp fall in gradient probably accounts for the wide meander plain witnessed between the Hakra course near Fort Derawar, through the Raini and Wahinda remnants area, to the northern reaches of the Nara Nadi. It is likely that as the river's course turned toward the southeast its heavy seasonal floodwaters would have overtopped its banks on the river's left bank (eastern side), flooding and depositing sediment over a large area to the east-southeast. The river's flooding also left behind many small basins, locally known as *dhand*, some of which could hold water for close to a year.

South of the Raini and Wahinda courses, the Nara Nadi flowed due south. At the present-day location of the Jamrao Head, the Nara's course ran toward the southeast and followed a path which skirted the western edge of the Thar Desert to the Rann of Kachchh.

### *Prehistoric Coastline of the Lower Indus Basin*

The present-day Indus River delta consists of two main parts: a coastal belt of marine tidal deposits, and an extensive estuary plain deposited by (fresh water) Indus River distributaries (Jalal-ud-din *et al.* 1970a and b). The Indus delta has grown considerably since the end of the Pleistocene as alluvium was deposited by the river's distributaries. The ancestral and present-day Indus deltaic distributaries and spill channels are concentrated in the south-central and southwestern portion of the Lower Indus Basin (Fig. 10 and 11). The courses of these Indus distributaries and spill channels have been traced from aerial photo composites of the southern plain and have been dated with corroborative historical evidence (Holmes 1968; LIP 1965a — Volume 2).

Correlated with the prior river courses of the Lower Indus Basin the deltaic areas of the Jacobabad Course and the Sindhu Nadi were different from that of the ancestral and present-day courses of the Indus River. Following the Sanghar and the Samaro-Dhoro Badahri remnants, the ancient or prior deltas were located in the southeastern portion of the Lower Indus Basin. Brinkman and Rafiq have estimated that during the Early Holocene "the estuary plain and the coast of the Lower Indus Basin slowly moved south from (a location) probably some distance north of Hyderabad to their present positions, and river plain sediments gradually overran the northern fringe of the estuary plain" (Brinkman and Rafiq 1971: 18; see Pithawala 1936: 307 and 1959: 48, for a similar viewpoint). This Early Holocene delta and coastline location seems congruent with the fluvial evidence of the Sanghar remnant, or distributary of the Jacobabad Course. Rapid vertical and lateral accretion of sediments from the Jacobabad Course and the Nara Nadi in the east-central and southeastern Lower Indus Basin advanced the delta southeasterly during the Early Holocene. During this delta building process, a fairly large portion of the south-central and southwestern Lower Indus Basin was probably estuarine.

The delta of the Sindhu Nadi (Middle Holocene) can be expected to have been located in the southeastern portion of the Lower Indus Basin (following the Samaro-Dhoro Badahri Course). Distributary sediments can also be expected to have moved the estuary southward, somewhere south of Hyderabad. Raikes (1964) suggested that the coastline may have been located near Amri during the fourth and third millennia B.C. Lambrick (1967, 1975) has rejected this notion and calculated that the coastline should more accurately be placed close to the thirty feet (9.144 m) contour line of the Lower Indus Basin; that is, and average sixty miles (96.55 km) inland from the present-day

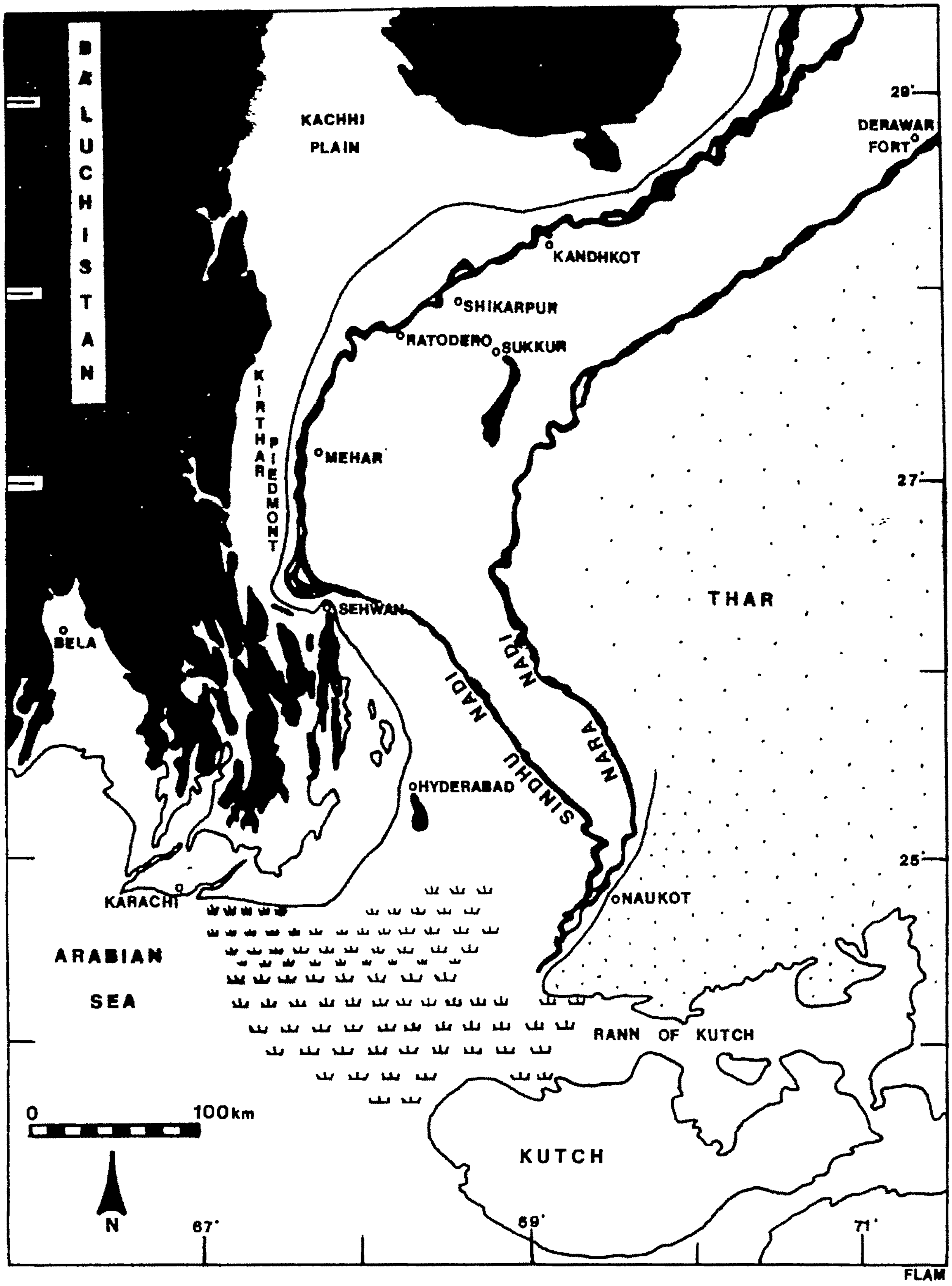

Fig. 17. Paleogeography of Sindh (c. 4000-2000 B.C.)

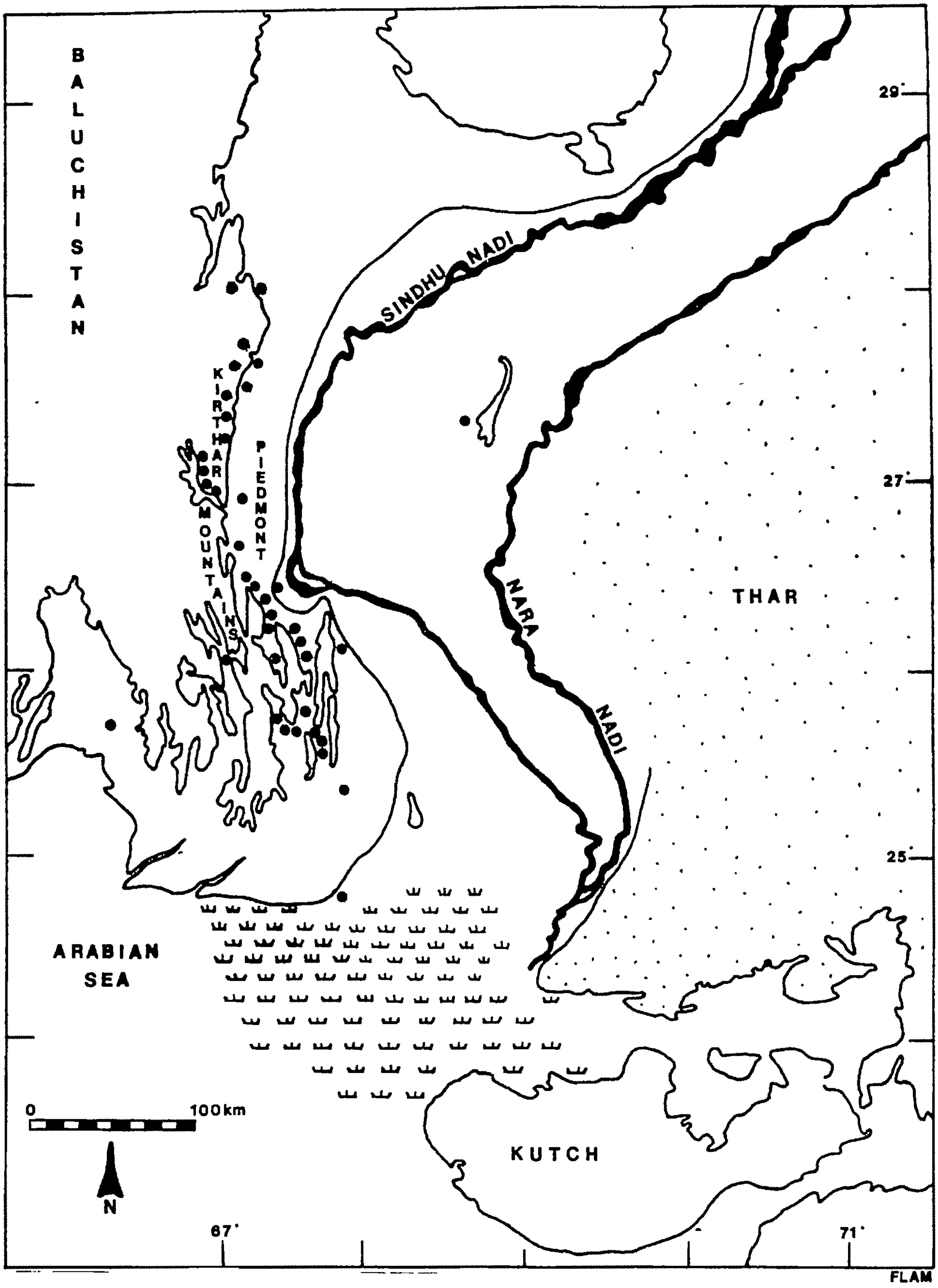

**Fig. 18**: Prehistoric sites in the Lower Indus Basin

location. If Raikes' estimate seems too far north, Lambrick's estimate may be too far south. Lambrick based his estimate on present-day contours of the Lower Indus Basin, and on estimated rates of alluvial aggradation for the Indus River; aggradation rates were derived from those rates for the Nile River in Egypt. Also, Lambrick assumed that rates of alluvial aggradation in the Lower Indus Basin have been relatively constant throughout the history of the Indus River. Of course, this cannot be assumed for any river in the world. Additionally, it has been a common practice to compare rates of alluvial aggradation of the Nile River with that of the Indus River. There is simply no scientific basis for this assumed comparison. The sources of sediment, amount and type of sediment load, regime, gradient, and channel morphology for the two rivers are neither immediately not manifestly comparable.

Siveright (1907) argued that the Rann of Kachchh was the delta of the Nara Nadi, and Blanford (1876) concluded that an inlet of the Arabian Sea, of which the *rann* was a part, extended a considerable distance northward into the alluvial plain of the southeastern Lower Indus Basin. It has been further suggested that the Rann of Kachchh and the Little Rann of Kachchh, as extensions of the Gulf of Kachchh, were inlets of the Arabian Sea (Allchin *et al.* 1978; Blanford 1876; Fedden 1884; Siveright 1907; Spate and Learmonth 1967). Thus, terrestrial Kachchh would have consisted of an island, or islands, completely surrounded by a tidal and seasonal sea. More field research in this area is required for a proper assessment of the role of the Rann of Kachchh in the palaeogeography of the Lower Indus Basin.

In consideration of the above discussion any delineation of the Lower Indus Basin coastline during the fourth and third millennia B.C. can only be provisional, awaiting further scientific research. For purposes of the present study, the precise delineation of the Sindhu Nadi and Nara Nadi delta and the coastline of the Lower Indus Basin have been purposely left vague.

Figure 17 presents a map of the Lower Indus Basin during the fourth and third millennia B.C. as reconstructed from research in the present study.

### Archaeological Implications

The location and fluvial behaviour of the Sindhu Nadi and the Nara Nadi had important consequences for human settlement and subsistence in the Lower Indus Basin during the fourth and third millennia B.C. The distribution of prehistoric sites can be grouped according to their proximity to the prehistoric river courses and coastline of the region (Fig. 18). Of the twenty-four presently known prehistoric sites located on the alluvial plain of the Lower Indus Basin, ten can be associated with the Sindhu Nadi (including Mohenjo-Daro), nine sites with the Nara Nadi, and four sites with the prehistoric coastline (as proposed herein). Three sites were neither close to the major rivers nor to the prehistoric coastline, but may have been located near a distributary or overspill channel of the Sindhu Nadi. Before the beginning of the mature Indus Civilization in Sindh (c. 2600 B.C.) only one prehistoric settlement was located on the alluvial plain of the Lower Indus Basin, the site of Kot Diji (Fig. 19). This is remarkable because adjacent regions (e.g., the Kirthar Mountains and subjacent piedmont plain, Sindh Kohistan, Baluchistan, and Cholistan) were extensively occupied. During the mature Indus culture, twenty-four settlements were created in the Lower Indus Basin (Flam 1981a and b, 1986a) (Fig. 20). This dramatic change in settlement pattern has yet to be fully explained, but there can be little doubt that the Sindhu Nadi played an important role.

When first encountered in prehistory the enormous scale of the Sindhu Nadi and its flood plain must have been an impediment to human settlement. Even after the beginning of the mature Indus culture, settlement of the Indus alluvial plain was not dense. Presently available archaeological evidence indicates that a greater density of mature Indus cultural settlements was in the Cholistan region (Mughal 1993). Perhaps the reason was that the scale of the Hakra was much smaller than the Sindhu Nadi, in terms of the morphology of their respective flood plains and the discharge of the respective rivers. The Hakra discharge was most likely on a scale similar to one of the Punjab's rivers listed above. Aerial photo composites clearly show the Hakra to be a narrower, shallower, and less sinuous channel than the Sindhu Nadi. In the Lower Indus Basin, the problem was how to protect settlements from large scale annual floods of the Sindhu Nadi and how to use available water supply for cultivation. To date, no evidence of large scale irrigation works have been discovered in the Lower Indus Basin.[14] The traditional *sailabi* method (natural river inundation), which is dictated by discharge and flood cycle, hydraulics, and patterns of water

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13 "As the Indus delta continues to grow, the part farthest inland becomes raised above tidal level, forming a plain which is deltaic in origin but no longer part of the tidal delta. The Indus soon effects modifications on this land surface which make it more characteristically riverine than deltaic (Fraser 1958: 140; see also Bates 1953, Moore and Asquith 1971).

14 During my study of the aerial photo composites of the Lower Indus Basin and adjacent regions I was particularly looking for any traces of evidence of a canal system which could be associated with the prehistoric settlement patterns of the regions; none were found. Thinking that any traces of canals might have been covered over by the approximately four thousand years of alluvial aggradation in the Lower Indus Basin since the mature Indus Civilization, I proceeded to investigate their possible occurrence in association with the Hakra River in Cholistan. Since the Hakra has been a "dry" river for about four thousand years and was characterized by a degrading flood plain, I looked to the Cholistan area to provide evidence of a large scale prehistoric canal or irrigation system; none was found on the aerial photographs of the region.

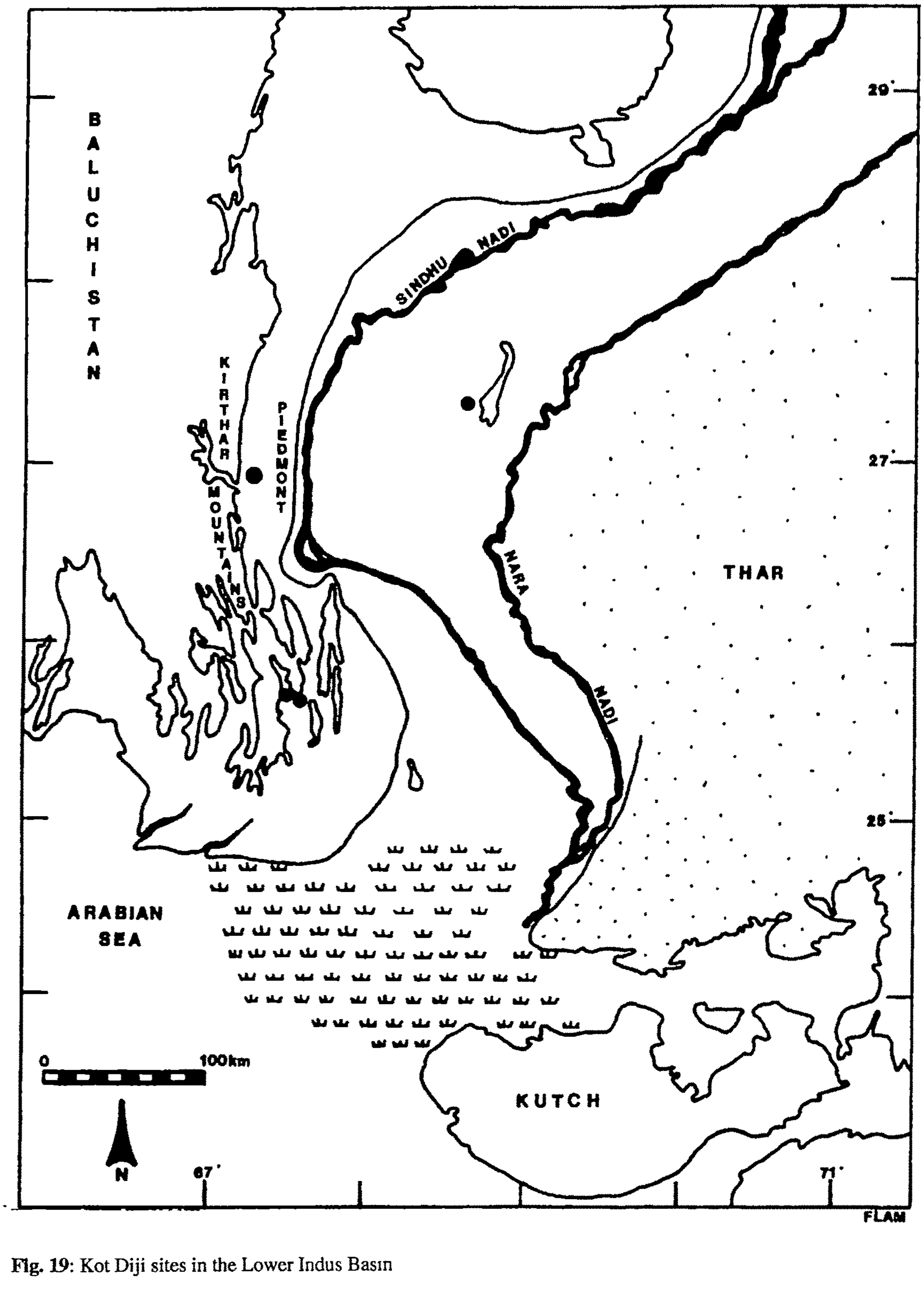

**Fig. 19**: Kot Diji sites in the Lower Indus Basin

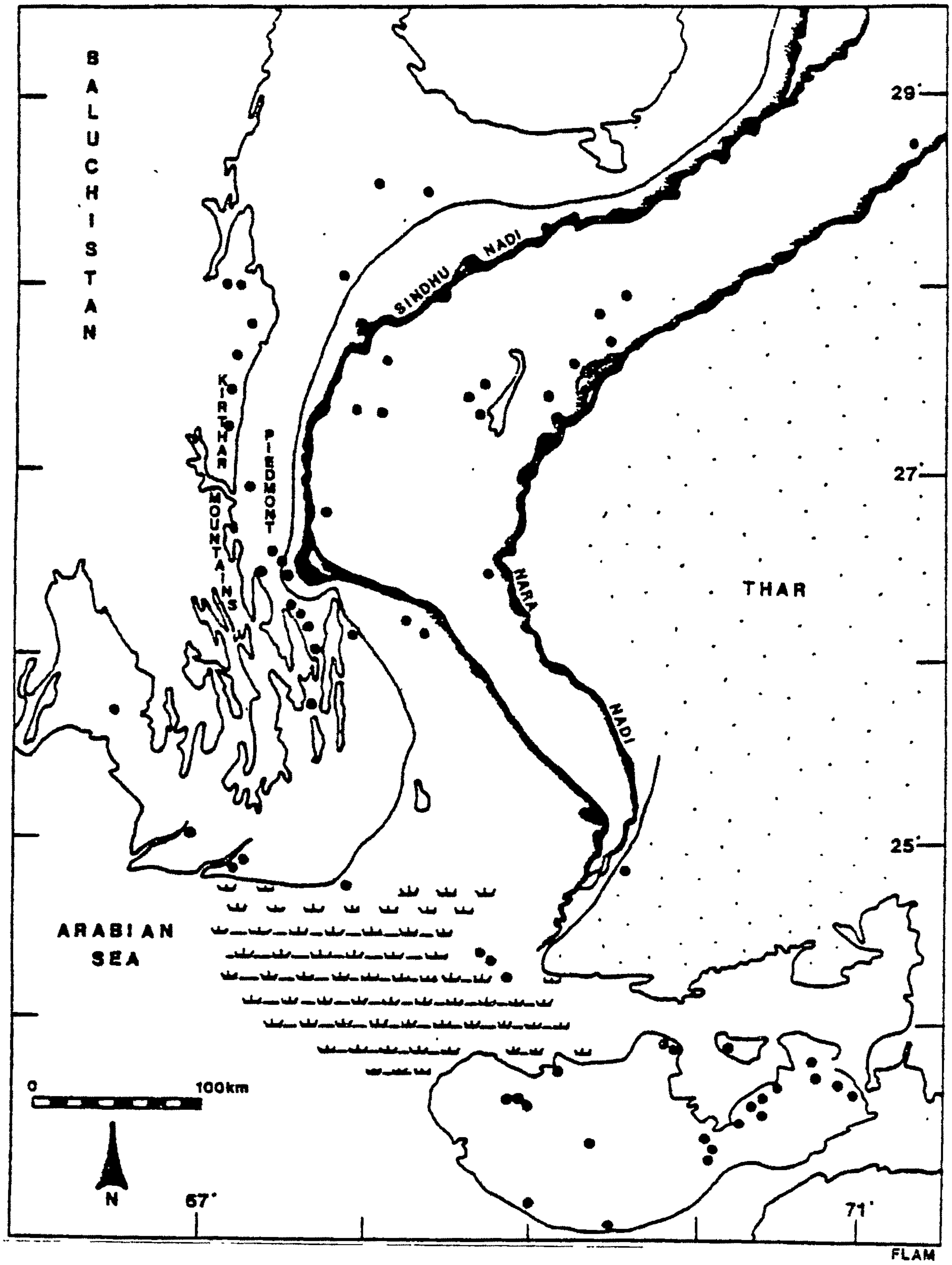

Fig. 20: Mature Indus valley site in the lower Indus Basin

distribution inherent in floodplain contours of the region, was probably the means of "irrigating" cultivable areas of the alluvial plain during the third millennium B.C. (Flam 1986a: 69-72). The ultimate reason for the settlement of the alluvial plain during the mature Indus Civilization may be related to changes in subsistence requirements (Flam 1981b), a shift in importance from overland to riverine socio-economic interaction routes (Flam 1981b, 1986a; Shaffer 1982), or population growth (Flam 1975).

Salient archaeological implications associated with the delineation of the Sindhu Nadi are relevant to the location of prehistoric sites in the Lower Indus Basin. The large channel morphology and discharge of the Sindhu Nadi is reflected in the archaeological record by sites located at a distance away from the main channel of the river, possibly along now untraceable distributary channels. Three scenarios relevant to prehistoric agriculture were possible given the distant location of many sites away from the main river channel of the Sindhu Nadi. The site of Mohenjo-daro can be used as an example. First, contours of the Lower Indus Basin in northwestern Sindh follow a northwest to southeast, as well as a north to south, fall in gradient from [the present-day cities] Sukkur to Dadu (Flam 1993b; Jorgensen *et al.* 1993: Figure 15.3 A; Lambrick 1964: Map 1). Deutsch and Ruggles (1978) have documented the magnitude of modern Indus floods even with engineered controls on the river's discharge (barrages, canals, and embankments).Their research found that the flood waters of the Indus covered an area between ten to twenty kilometres in breadth on both sides of the present-day Indus River. In prehistory, without the large scale regulatory controls of the present-day, over bank sheet flooding during flood stage from the Sindhu Nadi channel would have reached the proximate area around Mohenjo-daro by natural land contours. The July-August flood season and the October-November agricultural sowing season were perfectly timed, rendering large scale irrigation unnecessary to cultivate winter crops. In addition, Mohenjo-daro is located on a Pleistocene landform and this natural elevation raised the settlement above sheet flooding of the surrounding alluvial plain, and was a contributive reason for the placement of the settlement at that location in the Lower Indus Basin. Second, in the context of the surface contours, distributary channels of the Sindhu Nadi would have followed northwest to southeast courses (at least in the area of Mohenjo-daro; of course, other areas of the Lower Indus Basin would be different), from the river toward Mohenjo-daro. Small scale irrigation channels could have been dug to carry distributary water to prepared agricultural fields. Third, the importance of relatively small, low-lying basins in the alluvial plain cannot be underestimated. These low-lying basins, known as *dhand*, become filled with water during the flood season. A *dhand* can contain residual flood water throughout the year, depending on its size and depth. The *dhand* can also be home to fish and fowl and, very importantly, can trap water from river flooding that can be used weeks or months later to irrigate agricultural fields during the winter sowing and cropping season. In this latter scenario, a very small irrigation channel cut into the alluvial plain will suffice to cause the water in the *dhand* to flow a short distance to prepared agricultural fields.

There is clear archaeological and geomorphological evidence that sometime near the end of the third millennium B.C. the Hakra River was captured by the Gangetic system and the Sutlej River discharge was diverted to the Indus system. A change of that magnitude probably brought about a major transformation in the mean annual discharge of water and sediment in the Sindhu Nadi, and concomitant changes in the paleohydrology (long term discharge of water and sediment), channel morphology (width, depth, slope, shape, pattern), and flow characteristics (depth, velocity, turbulence) of the river (see Schumm and Lichty 1965). Coupled with evidence that the northwestern portion of the alluvial plain has been tectonically active for thousands of years (Jorgensen *et al.* 1993), a major change in the Sindhu Nadi course near the end of the third millennium B.C. can be hypothesized, and is indeed documented by fluvial remnants in the Lower Indus Basin. If the river shifted its course from the Sindhu Nadi to the Kandhkot Course during the prehistoric occupation of Mohenjo-Daro, the city would have been placed in a precarious location too close to the unrestrainable floods of the ancestral Indus River. This change in the main river channel would have brought widespread abandonment of many sites and a movement of population out of the Lower Indus Basin into adjacent and more "stable" areas. Total abandonment is not hypothesized in this context, but rather an adjustment to natural geomorphic transformations. Human populations probably redistributed their settlements but at a renewed scale and density of distribution, which is what is found in the archaeological record.

## Summary

Natural transformations as well as human attempts to regulate the fluvial environment of the Lower Indus Basin have brought great changes in the environmental configurations of the region during the Holocene. Equating present-day configurations with those of the fourth and third millennia B.C. is erroneous and misleading when used to interpret the ecology of cultural dynamics and adaptation in the Lower Indus Basin.

Toward reconstructing the fluvial configurations in the Lower Indus Basin during the fourth and third millennia a chronological sequence of fluvial "events" has been presented. Two "prior" river courses of the present-day Indus River have been delineated — the Jacobabad Course and the Sindhu Nadi. In addition, one "ancestral" course of the present-day Indus River has been delineated — the

Kandhkot Course. The Sindhu Nadi has been recognized in this study as the former course of the Indus River during the greater parts of the fourth and third millennia B.C. The Sindhu Nadi has been traced in the northwester, central, and southeastern portions of the Lower Indus Basin from remnants visible on aerial photo composites and confirmed by ground observations.

In addition to the Sindhu Nadi, the Nara Nadi has been recognized as an exclusive perennial river which flowed in the northeastern, east-central, and southeastern portions of the Lower Indus Basin during the fourth and third millennia B.C. Traces of the Sindhu Nadi and the Nara Nadi indicate that in the southeastern portion of the Lower Indus Basin the two rivers formed a confluence and flowed as one river in the area south of the present day town of Naukot. Available evidence suggests that during the fourth and third millennia the delta of the combined Sindhu Nadi and Nara Nadi was located near the Rann of Kachchh on the eastern side of the Lower Indus Basin to somewhere between Hyderabad and Thatta in Sindh.

Archaeological evidence reveals that the Lower Indus Basin was not extensively occupied until the middle of the third millennium B.C. Presently, evidence of a major canal or embankment system to control or divert discharge of the Sindhu Nadi and Nara Nadi is lacking in the Lower Indus Basin. It has been reasoned that control of the river's discharge was not a necessary prerequisite for agriculture in the Lower Indus Basin, and that the traditional *sailabi*, or inundation, method was used during the third millennium. Mohenjo-daro, the largest prehistoric settlement in the Lower Indus Basin was located approximately twenty-five kilometres southeast of the Sindhu Nadi Course. The city may have been abandoned after the river shifted its course to a location more closely aligned with the present day Indus River, placing Mohenjo-daro in the imperiled position of bearing the brunt of the river's annual floods.

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# On the Nature of the Indus Seals: Problems and Prospects

P.V. Pathak

Parijat
48 Lokamanya Housing Society
At Post Pen
District Raigad 402 107

### Abstract

Although several hundred attempts have been made by both professionals as well as amateur researchers of very varied backgrounds to decipher the Indus script, very few, out of the more than 2,500 Indus seals and sealings have been deciphered or understood in their proper background. The author attempts to analyse and understand the iconography of the seals rather than decipher the Indus script. He has also reviewed the work on seal decipherment. In addition his own interpretation of these legend seals as the pictorial representations of the Atharva Vedic (AV) hymns has been discussed.

## Introduction

One of the greatest discoveries in the field of archaeology in India was the discovery of the Indus civilization. Although, it has extended the age Indian civilization backwards by more than 3000 years prior to the date of Lord Buddha, it has also created a puzzle for archaeologists and Indologists. Excavations at various Indus cities, though they have thrown more and more light on the material culture of the times, have, however, yielded little understanding of their language and culture.

The major Indus culture sites have yielded several Indus seals with pictures and graffiti engraved on them. These challenged scholars since the day they were discovered. Several hundred attempts have been made by both archaeologists and amateurs to decipher the script and understand it, but this has remained a very controversial problem and there is no unanimity among scholars on the script decipherment.

It is to be noted here that major research efforts on the Indus seals have been directed towards script decipherment and very feeble attempts have been made to understand the pictorial representations. There have been several review papers on the script decipherment such as that of Zvelebil (1985: 151-187), but hardly any attempt has been made to understand the pictures, legends, etc. engraved on the Indus seals. A review of the nature and the pictorial description on the Indus seals is given here.

## Corpus of the Seals

So far three concordances have been compiled by Russian, Finnish and Indian scholars. One of these and the only exhaustive compilation '*Corpus of the Indus Seals*' — in two volumes by Joshi and Parpola for the seals in India (Vol. 1) and seals in Pakistan by Shah and Parpola (Vol. 2) — is referred to here. These volumes give the picture of the original seals, their mirror impressions and three-dimensional views. This two-volume monumental work has reported more than 2500 seals and sealings found in India and Pakistan upto 1990, and is to be acknowledged as a major contribution to the literature of the Indus culture.

Over the last seven to eight years a major excavation at Dholavira has yielded about 50 seals and the few seals available from other minor sites should be incorporated in the next or extended part III of this work which then can also include the seals found outside India and Pakistan. There are several original Indus seals and a few seals of the Indus type found at Middle Eastern sites, which must have been engraved by the local artists for persons of the Indus cultural origin, possibly merchants. Indus culture seals have been found at Kish, Ur, Susa, etc. in the Middle East. There are a few Indus seals in museums outside the Indian subcontinent. All these can be combined to constitute part of the proposed volume III of the *Corpus*.

## Shape and Origin

Material aspects such as the raw material of the seals, i.e. soft steatite stone, copper engraved, etc. have been described in the excavation reports and articles related to excavations.

It is to be noted that the countries in the Middle East had the practice of carving seals since pre-Indus times. The

Middle Eastern and Indus seals differ from each other in the following aspects.

1. A majority of the Middle Eastern seals are cylindrical while almost all the Indus seals are rectangular. Tiessier has reported more than seven hundred cylindrical seals (Tiessier 1984).
2. Many square shaped Indus seals are reported to possess a boss on the obverse side of the seal engraving.
3. There are a few cylinder-shaped Indus seals. One, prominent among these seals is from Kalibangan depicting a centaur-like figure and a central human figure with a bun (?) flanked by two large human figures making an arch over the central figure. Two more cylindrical seals, one each from Mohenjo-daro and Daimabad are reported.
4. The Indus seals carry mostly pictures of animals or graffiti. There are very few pictures showing human figures. There are only a few seals with multiple human figures which convey some myths or legends. The paucity of human figures makes it difficult to understand and decipher these seals. Seals in the Middle East, on the contrary, are profusely illustrated with human figures. They describe myths and legends. These could be deciphered and the human characters identified.
5. The seal-making technique and usage of seals in the Middle East started around 3200 B.C. The art of making seals and their use in India was prevalent only during the Indus culture period and was interrupted with the fall of the Indus Culture. The latest seal found at Daimabad, a late Indus site is dated to 1500 B.C.
6. Human features with distinct attire are observed on the seals from the Middle East which helps to identify the particular characters on these seals. There exist no such distinct features of the human figures on the Indus seals except for that on the famous *Pasupati* seal.
7. Many Indus seals carry only graffiti and are not accompanied by any picture while such seals are rare among the Middle Eastern seals.

The above seven features distinguish the Indus seals from the Middle Eastern seals showing the separate identity of the two regions.

## Classification of the Indus Seals

An earlier attempt at the classification of the animal seals in particular, was done by Atre (1990). She had expressed her views that the human figure on the *Pasupati* seal is the Lady of the Beasts. With that assumption she proceeded to classify the animal seals into four categories, namely, a) animals that may either be with a manger or without it, b) animals that are without a manger, c) animals never with a manger, and d) animals always associated with a manger. Thereafter, she comments (Atre 1990: 45), " The animal variety being, entirely tamable animals, totally domesticated — conveying supreme command of the goddess over animal world and also gradation in her regime. Indeed, the restrained static posture is the only clue to assert that though it does not hold exactly a subordinate position to the goddess, it neither assumes a superior position of the male spouse. It might have been assigned a special status of a fecundating agent of the goddess." The present author has refuted the 'Mother Goddess' hypothesis by Atre (Pathak 1991). Her theory on the role of the animals is entirely speculative.

The seal classification proposed in Table 1 is on the basis of seal engraving.

## The Legend Seals

Apart from the above seals there are other seals which can be classified as legend or myth seals. This class of seals could really provide clues for our understanding of the origin of the Indus culture. These legend seals can be defined as seals bearing more than one animal or human figure and convey some message or legend either from the ancient Indian or Middle Eastern region. These legend seals, some of which are dealt with below, have obviously attracted the attention of scholars.

### *Gilgamesh seals*

There are three seals from Mohenjo-daro (M-306, M-307 and M-308) bearing Indus graffiti on the top. These seals depict a human figure holding two tigers at bay. This is a representation of the Gilgamesh myth from the Middle East. The seal can be compared with the uninscribed Gilgamesh myth seal showing a royal figure holding lions at bay (Tiessier 1984: seal no. 290) dated to around 521-450 B.C. i.e. the Achaemenian period (Tiessier 1984: 182).

A lion appears on many seals from the Middle Eastern civilisations. The Indus seal points to its origin being in India, because two tigers and not lions are engraved on these seals. Although the graffiti on the top differs, the pictorial inscriptions are similar.

In the Middle East there are variations of the animals held at bay by the hero dating both to the Akkadian and post-Akkadian period (2334 B.C. to 2154 B.C.), and the Achaemenian period (542-450 B.C.) (Tiessier 1984: 182). The seals of the earlier period are: (i) hero standing between two pairs of antelopes fighting with lion on each side (seal No. 73), (ii) bearded bull (seal No. 75), (iii) hero attacking a lion attacking a bull (seal No. 76), (iv) hero attacking water buffalo and bull-man attacking a lion (seal No. 78); while seals of the later period are (v) hero holding

**Table 1**:

| No. | Class of Seal | Remarks |
|---|---|---|
| 1 | Sacred humpless bull with single horn and filter in front | This is the most important class and more than 40% of the total number of seals (1082 out of 2500) belong to this category. |
| 2 | Sacred humpless bull with two horns with flat manger and sacred filter in front | This class of seals is another major type, numbering 89. |
| 3 | Multiple-headed sacred bull | These seals bear a single bull body with two or three bull heads which are single as well as double-horned. There is a single circular seal M-117 with a six-horned bull joined together. There are seven such seals. |
| 4 | Typical Brahmi bull with prominent hump | This is the third largest class with 53 seals reported. It is to be noted that none of these Brahmi bull seals have a sacred filter engraved in front of the bull figures. |
| 5 | Animal figure | There are numerous animal figure seals depicting individual animals including tigers, elephants, rhinoceroses, goats, buffaloes, and occasionally camels. The only reptiles engraved on the seals are cobras and crocodiles. Lions which had a natural habitat around the Gir forest in Gujarat are absent as are birds except for a single eagle seal from Harappa (H-166). The horse, a controversial animal, is totally absent. |
| 6 | Swastika | There are seven such seals. This is another large group where the swastikas are of both types i.e. clockwise and anti-clockwise. It appears that the swastika symbol was accorded a sacred status which has continued till today. |
| 7 | Decorative designs and secular pattern | The decorative patterns include chequered rectangular patterns, small circles in rows and beam matrices, concentric circles with a dot at the centre. Three circular seals with different decorative patterns from the above-mentioned are unearthed from Zhukar. Puzzle-like patterns with the endless knot motif are present. |
| 8 | Multiple animals | Many seals carry pictures of many animals either of the same species or of different species. A rectangular seal with two bulls locking horns (M-1352), another seal bearing a picture of two deer, etc. are the seals of the first kind. There are many seals which bear pictures of different animals. |

| | | |
|---|---|---|
| 9 | Tree and plant species | Apart from drawings of plant species on multiple figure seals, there are a few seals bearing pictures of single plant species. These are vertical plants with lots of branches and foliage like H-183 to H-195. A few small seals bear pictures of Pipal (*Ficus religiosa*) leaves. |
| 10 | Exclusive graffiti | This is another large class of seals. A majority of these seals are rectangular in shape but a few are circular. There are 247 seals of this type. Graffiti on some of these seals is totally obliterated and some bear script symbols posing a real challenge to scholars and researchers of various disciplines. |
| 11 | Hunter and tiger hunting | A few copper tablets from Mohenjodaro bear the picture of a hunter with bow and arrow (M-582 to 588). There are 12 seals bearing the image of a tiger and a hunter sitting on a tree behind the tiger. The tiger is seen to be looking backwards at the hunter. |
| 12 | Centaur seals | A chimera-like figure with an animal torso attached to a standing human figure has been found at Mohenjo-daro (M-311), Kalibangan (K-50) and on a cylinder type seal (K-65). The rectangular seal from Mohenjo-daro and Kalibangan bears an inscription of two script signs while the cylindrical seal from Kalibangan does not bear any script signs. |

at bay two winged bulls (seal No. 289), (vi) hero holding at bay two sphinxes (seal No. 291), (vii) hero holding at bay two ibex-men (seal No. 292), and (viii) hero holding at bay two ibexes (seal No. 293).

There is no parallel to the Gilgamesh legend in Indian mythology. Hence the idea of this seal appears to have its origin in the Middle East although it was engraved in India. Knowing that it is a Gilgamesh seal has not yet helped to decipher the script on the top. There is only one sign, common between the two seals namely, M-306 and M-307.

It is likely that these seals were engraved by a trader who was from the Middle East and hence, influenced by the myth and that he carved the insignia for himself and exported goods to the Middle East bearing this stamp. It is also possible that an Indus merchant, having travelled to the Middle East was influenced by the myth but had his seals carved with an Indian tiger.

## Legend Seal Decipherment

The Indus seals were studied in depth by many scholars and one of the first attempts at understanding these seals was Waddell's as early as 1925 (Waddell 1925). He called these seals the Indo-Sumerian seals. He proposed that the seal which depicts a hero slaying a lion is a representation of Izzax, King of Erek (c. 3100 B.C.) who was the father of Urus (Sanskrit Haryasva), king of the Indus valley and founder of the first Phoenician dynasty (Waddell 1925: Fig. A). He drew parallels between the Indus, Sumerian and Phoenician scripts and gave syllabic sound attributes to the Indus signs. He read the names of the Rgvedic and Puranic deities on the seals. He has emphasized the importance of trying to understand the Sumerian seals with reference to the deities.

Another scholar who endeavoured to understand these legend seals was Buddha Prakash (1966). He proposed that there was internal social conflict in the Indus valley between the working classes and the economically stronger sections. The villages of the Indus culture rose against the city dwellers who were exploiting them and destroyed the cities (Buddha Prakash 1966: 95-96). While interpreting the famous *Pasupati* seal he agreed with Deshmukh (1958: 41) that the deity represents the three-headed six-eyed semi-god *Visvarupa Tvastr* mentioned in RV X.996 where all the beasts shown round the central figure belong to him (RV III.55.19 and SB III.7.3.11 and VIII.8.11). Similarly, he interpreted the Gilgamesh seals as representing the Vedic idea of the antagonism of order and disorder in nature (Buddha Prakash 1966: 44). He has similarly interpreted some more Indus seals as representations of Rgvedic myths.

Fateh Singh (1968) proposed that the spiritual metaphors from the Brahmana and Upanisadic texts are symbolically depicted on the Indus seals.

The above three scholars have attempted to interpret the seals using the Vedic literature, especially the Rgvedic literature. There is another school of thought which has explored the possibility of interpreting the seals presuming that these have an old Dravidian language background. Zvelebil, Fairservis, Parpola, Mahadevan and the Soviet scholars Alekseev, Knorozov, Kondratov and others, are some of the prominent proponents of the Dravidian hypothesis. All of them have attempted to decipher the Indus script assigning phonetic or ideographic value to the Indus graffiti symbols and have then interpreted the seals.

Fairservis having assigned certain phonetic values from Tamil to the Indus symbols, however, has given a general interpretation of the legend seals bearing in mind the customs in south India and sometimes, if possible, in particular those from Tamilnadu (Fairservis 1992: 198-223). He offers an interpretation of the famous *Pasupati* seals as representing chiefs or deities wearing typical headgear to be worn by the person wielding paramount power. Such a person may be a chieftain. He controls the large herds, especially of cattle and has control over the grazing lands. He has interpreted the centaur seal from Kalibangan similarly (Fairservis 1992: 205). At times Fairservis refers to the Tamil words in the Dravidian Etymological Dictionary to substantiate his claims. He has offered an interpretation for 71 Indus legend seals. These interpretations are not cogent.

Asko Parpola's work on the Indus seals starts with the premise that the fish sign on the Indus seals represents a star in the sky. He offers an explanation for this proposition as "... the conception of stars as fish swimming in the waters of the night sky is attested in old Tamil text *Paripatal* (16, 36.8), where the river *Vaiyai* is compared to the heavenly Ganges with its fish (*min*). The Ganges, the holiest river of India, is so sacred because it is believed to have descended from heaven" (Parpola 1994: 181).

According to Parpola the single fish sign represents a symbol for the god of water, while 7+fish (*elu+min*) represents the Ursa major constellation, the fish with roof (*may+min*) represents Saturn, the dark star (Parpola 1994: 275).

When it comes to interpreting the legend seal from Mohenjo-daro bearing the picture of a goat, a man with a head-dress and a human figure with a head-dress under *pipal* canopy and seven human figures at the bottom, Parpola takes recourse to Vedic myths and Puranic legends. He offers multiple interpretations for the same seal. According to Parpola, a) the fig tree on the seal represents sacred marriage, like the marriage of *Urvasi* and *Pururvas* (RV X.95), b) if one considers the tree to be a banyan tree, it must have relevance to the *Sunahsepa* legend in the Rgveda (RV I.24) and in the *Brahmana* texts (*Aitareya Brahmana* VII.13-18), c) the kneeling central human figure is sacrificing a buffalo and the ornamental Markhor goat behind represents the "predecessor of the goat-faced Hindu god Skand whose name (attested to since the late Vedic period, *Chandogya upa.* 7) means 'the leaper'. The Markhor is famed for being able to jump to inaccessible places," d) the seven figures below represent the seven mothers of Skanda, e) the goddess inside the figure canopy represents the goddess *Rohini* (Parpola 1992: 228-231).

Can one read so many ideas from diverse regions and extending over a period of centuries on a single seal? Does Parpola agree that the *Upanisada* precedes the Indus culture? The present author had in the same year given an interpretation of the same seal as a pictorial representation of the Atharvaveda hymn IV.37 (Pathak 1992). He has made a reappraisal of Parpola's views (Pathak 1995b).

Another attempt at finding the Dravidian roots of the Indus culture has been made by Madhivanan (1994) who attempted to assign Tamil proper names to some of the Indus seals. He has drawn parallels between Tamil and Sindhi proper names, thereby pointing to a common root for both the languages.

All the above attempts have not met with unanimous approval from scholars who have referred to the various texts to substantiate their claims, but have not been able to offer cogent explanations referring to any specific parallel from a Sumerian text or a hymn from the Vedic *samhita* or even Tamil texts. They have not explained the ritualistic, religious or magical significance, or the specific purposes of these seals.

Another approach, independent of any textual reference has been followed by During-Caspers. She selected the copper seals from Mohenjo-daro depicting hunters with bows and arrows. She proposed that these hunter figures are shown to be wearing bull-horned masks and tails. She refers to the bull-eared and bull-horned human clay mask from Mohenjo-daro. She concludes that the Indus culture people used these masks as magical hunting rituals (During-Caspers 1985: 227-236). Correlating these seals and masks with the *Pasupati* seal, she states, "The four wild animals, including the tiger, which surround the magic hunter, as we may now propose to call the central figure, can be explained simply as the hunter's prospective game which he brings under his spell in a ritual dance, as are the goat or gazelle-like animals under his stool" (During-Caspers 1985: 235).

Having interpreted the *Pasupati* seal himself the present author would like to comment on the above interpretation given by During Caspers.

The *Pasupati* pose is certainly not the dancing pose. It is one of the *yogasana* postures called *yonyasana*. The *phallus erectus* position of *Pasupati*, in spite of pointing to hunting dance, points to his being the procreator of the universe releasing the seed of the universe, *pramuncato bhuvanasya retah* (AV II.34). The human figure on the seal above the tiger cannot be equated with a hunting game.

## Indus Seals and the Atharvaveda

Over the last few years the present author has explored the possibility of correlating some of the legend seals as classified by him with the Atharvavedic hymns. He has correlated:

a) the *Pasupati* seals as being a pictorial representation of the AV hymn II.34 (Pathak 1991: 57-64);

b) the seal of three forms and seven figures i.e. M-1186 referred to earlier, as a pictorial representation of the AV hymn IV.37 (Pathak 1992: 59-63);

c) the men and tiger seal (No. M-1425) as being a pictorial representation of the AV hymn IV.3 (Pathak 1997: 38-43);

d) the sacred bull in front of the sacred filter seals and the bull man seals (seal No. M-1224) as being the royal emblems as described in AV VI.86 (Pathak 1998); and

e) the seals bearing a bull torso with multiple heads as being a pictorial representation of AV hymn V.16 recited at the time of royal consecration (Pathak 1998).

The present author suggests that the pictures on these seals illustrate particular *rcs* of the Atharvaveda. He has also explained the significance of the most common seal of the sacred bull with sacred filter in front to be the royal emblem. It had to be used as the seal of authority in the Indus period. This explains the need for engraving these seals in such large numbers.

It is now left to scholars of the Indus culture, researchers both professional and amateur, and historians to critically evaluate the present author's approach. If found valid, then he urges them explore the possibility of correlating other aspects of the Atharvavedic society and cultural ethos with the Indus cultural ethos.

## Acknowledgements

All the references to the Indus seals are from the Corpus of the Indus Seals and Inscriptions in 2 volumes edited by Joshi and Parpola 1987, and Shah and Parpola 1991. The figures and the symbols are drawn by Shri Vasant Kumbhojkar.

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# Significance of a Bead Manufacturing Centre at Mahurjhari, District Nagpur, Maharashtra, India

R.K. Mohanty

Department of Archaeology
Deccan College
Pune 411 006

## Abstract

The various processes involved in bead manufacturing have been reconstructed from the study of manufacturing waste found at the Iron Age and Early Historical site of Mahurjhari. The evidence suggests that bead manufacturing was centrally organized, at least during Early Historic times when the recovery of rich cultural material indicates a flourishing economy.

## Introduction

Mahurjhari is a well known Megalithic burial site (21° 14' N; 79° 30' E), excavated for several seasons by Deo (IAR. 1958-59: 21; Deo 1973; *IAR* 1978-79: 71). A larger proportion of the burials at Mahurjhari are accompanied by grave goods compared to that of other burial sites such as Kamtee, Junapani, Borgaon, Raipur-Hingna and habitation-cum-burial sites such as Tekalghat-khapa, Naikund, Khairwada and Bhagimohari. Among these, Mahurjhari, Tekalghat-khapa, Khairwada and Bhagimohari continued to be inhabited during the Early Historic period. Deo (1973: 62) does not identify any evidence for settlement during the Megalithic period at Mahurjhari. A copper-plate, seals, intaglios, beads, bricks, pottery and other antiquities of the Gupta-Vakataka period (Hunter 1933; Kolte 1971; Deo 1973) have been collected from the Early Historic settlement at Mahurjhari. The exceptionally rich grave goods in the Mahurjhari megaliths remain to be explained in the context of the comparatively poorer grave goods found at other sites in the region, especially in the absence of a contemporary settlement. An extensive survey of the Iron Age and Early Historic site of Mahurjhari was carried out to address this problem. This survey provided evidence for a bead manufacturing centre as reported here.

## Previous Work

Evidence for bead manufacturing at Mahurjhari was first noticed by Hunter (1933), who had found a few unfinished beads in the historical mound (Vakataka Period c. 4th-5th. century A.D.) in the middle of the present village (locality IV). Some 500 m away from Mahurjhari village, there is the Megalithic burial ground (locality I), from where a few unfinished and finished beads were reported both from the burials and on the surface (*IAR* 1958-59: 21; Deo 1973; *IAR* 1978-79: 71). The other two burial localities (locality II and III) were not used as bead manufacturing areas. During an intensive exploration carried out in 1993-94, an extensive bead manufacturing factory locality (locality V) was discovered between the historical mound (Locality IV) and Megalithic burial ground of locality I.

## Chronology

There are no radiocarbon dates available for Mahurjhari. The Megalithic phase in Vidarbha is dated to c. 800-200 B.C. (Mohanty and Joshi 1996; Deo and Jamkhedkar 1982: 7-8). To assign an absolute date at present for the beginning of the Megalithic culture and manufacturing of beads at Mahurjhari is difficult. However, the finding of finished and unfinished beads from the Megalithic burial site and similar types of beads found on the surface of the recently discovered bead manufacturing locality suggest a date comparable to that of dates for the Vidarbha Megaliths. Tentatively, the antiquity of bead manufacturing at this site can be assigned to the Megalithic period beginning around 6/7th.century B.C. Intensive bead manufacturing was undertaken during the Early Historic period which continued up to 4-5th century A.D. (Vakataka period). The Early Historic mound and the manufacturing locality both have yielded large numbers of beads in different stages of production along with hoards of finished and unfinished beads coming from the habitation area. It is not clear at present whether this industry continued from the Iron Age up to the Early Historic period. According to Deo, "The unfinished state of these beads indicates that Mahurjhari was a bead-making centre in the historical period. That it was so even in the earlier period, going back to the Megalithic times, is further indicated by the discovery of

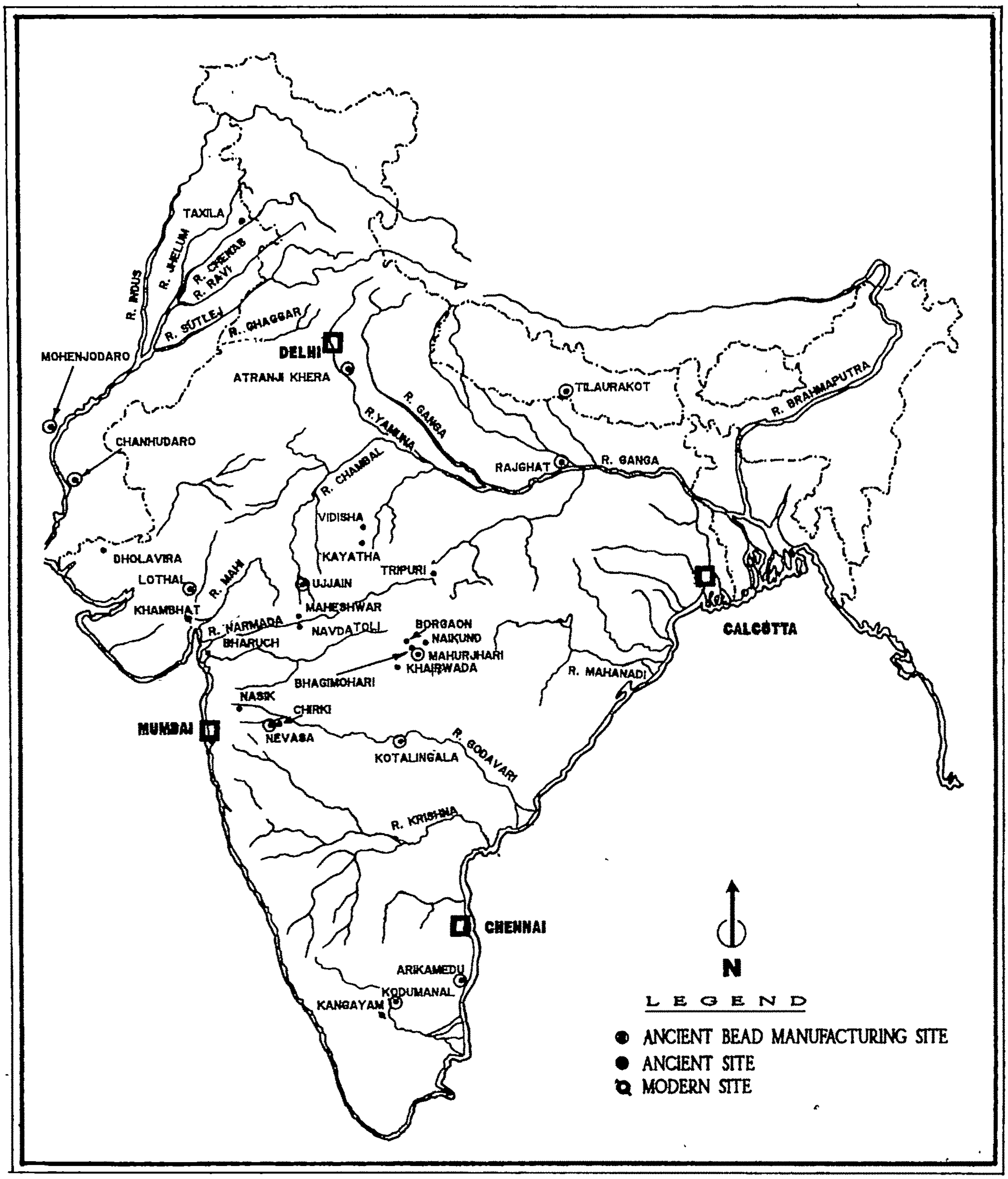

**Fig. 1**: Important bead manufacturing centres in ancient India

several unperforated etched and unetched carnelian beads in the Megalithic field..." (Deo 1973: 32). There is a strong possibility that it continued. If this can be proved by systematic excavation of all the bead manufacturing localities, we may have one of the longest histories for a lapidary centre found in an archaeological context. A trial trench measuring 1 m x 1 m was taken in the manufacturing area to understand the nature of the material remains under investigation.

## Significance of Beads and Manufacturing Centres

In the Indian context, beads of various raw materials are an important constituent of the assemblages of antiquities recovered from any exploration and excavation, at least from the Chalcolithic period onwards. Beads are the best preserved antiquities, especially beads made out of precious and semi-precious stones. In the bead assemblage from a site the presence of a few unperforated or unpolished beads without processing residue should not be taken as indicating a production centre. Based on this criteria, there are very few bead production centres identified from the several hundred excavated protohistoric and historic sites. Some of the important production centres belonging to different cultural phases are Mohenjo-daro (Kenoyer 1986; Tosi *et al.* 1984; Vidale 1985; 1989), Chanhu-daro (Mackay 1943), Lothal (Rao 1973), Arikamedu (Wheeler *et al.* 1946; Francis 1991), Ujjain (Banerjee 1959) Kotalingala (Sastry 1983) and Kodumanal (Rajan 1990) (Fig. 1). These centres have provided information regarding various methods used for bead manufacturing.

Precious stone beads were an exotic item, procured and used by comparatively wealthy people within a cultural complex in a settlement. Beads of cheaper materials such as terracotta, faience and glass, requiring less labour to produce or where mass production was possible with the available expertise, may have been used more commonly. Beads of stone and metal were probably the most expensive and possibly the higher cost was also due to labour intensive specialized manufacturing processes right from procurement to distribution. Hence, these beads could not be manufactured wherever they were used or required. Manufacturing centres were invariably guided by the expertise available, availability of sources of raw material, socio-economic conditions and the organization governing the production and marketing. Moreover, throughout the manufacturing process of stone beads, various kinds of expertise was required e.g. in the selection of good raw material, making bead blanks, working with bead blanks to give a desired shape, grinding, polishing and drilling. From the available archaeological records it can be inferred that only a few sites have evidence for the whole process of bead manufacturing from the procurement of raw material to the final stage of marketing.

## Mahurjhari Evidence

Mahurjhari is one of the few bead manufacturing centres in central India where such craft specialization could be seen over a period of several centuries. Ethnographic work carried out at the present day bead making centres in Khambhat (Kenoyer *et al.* 1991; Roux *et al.* 1995) and Kangayam (Rajan 1997-98) have helped in reconstructing bead making technology. Mahurjhari appears to have been a large-scale centralized bead production centre (Fig. 2). This is indicated by comparison with traditional bead production and the presence of refuse from all types of items from raw materials to finished products pertaining to each stage of production scattered in and around the workshop and habitation area. The debris accumulated from the large-scale production of beads over several centuries is suggestive of the relative prosperity of the Iron Age and Early Historic people of Mahurjhari. This is also reflected in the rich burial accompaniments at the site in comparision to other sites in the region (Deo 1970, 1973; Deo and Jamkhedkar 1982; Deglurkar and Lad 1992; Moorti 1994).

The Early Historic finds are also equally impressive (Deo 1973) reflecting a similar kind of prosperity. The copper plates belonging to Prithivisena II of the Vakataka dynasty (Kolte 1971), the intaglio (Deo 1973: 1 & Pl. II-A2) bearing the name of 'Sri Madhavaraja' and seals found from the site further reflect the importance of the settlement. This circumstantial evidence also suggests that the bead production centre was an industry centrally controlled by the ruling dynasty during the Early Historical period and may have been significant for the state economy.

The bead manufacturing debris occurs over the entire site but is concentrated in an area 500 m away from the main Early Historic habitational mound, over an area of about 90 x 50 m. This bead manufacturing locality has a deposit of about 25 cm consisting mainly of beads in various stages of manufacture and the refuse of manufacturing processes along with some finished products. The huge quantity of semi-processed raw material, beads in different stages of production along with debitage and material discarded during the manufacturing processes make this site one of the most important in understanding various aspects of manufacturing processes, expertise, technology, evolution of forms, specialization and finally distribution.

A random sampling of a 15 x 15 m surface area from locality V yielded 236 artefacts (excluding debitage) pertaining to various stages of the production process (Table 1, Fig. 3). The material so retrieved may not represent the actual amount of debris originally deposited on the surface as the villagers have been collecting this material especially the finished beads and bead blanks which eventually find their way to Nagpur market, "where these are sold after some polishing to be worn as ring-

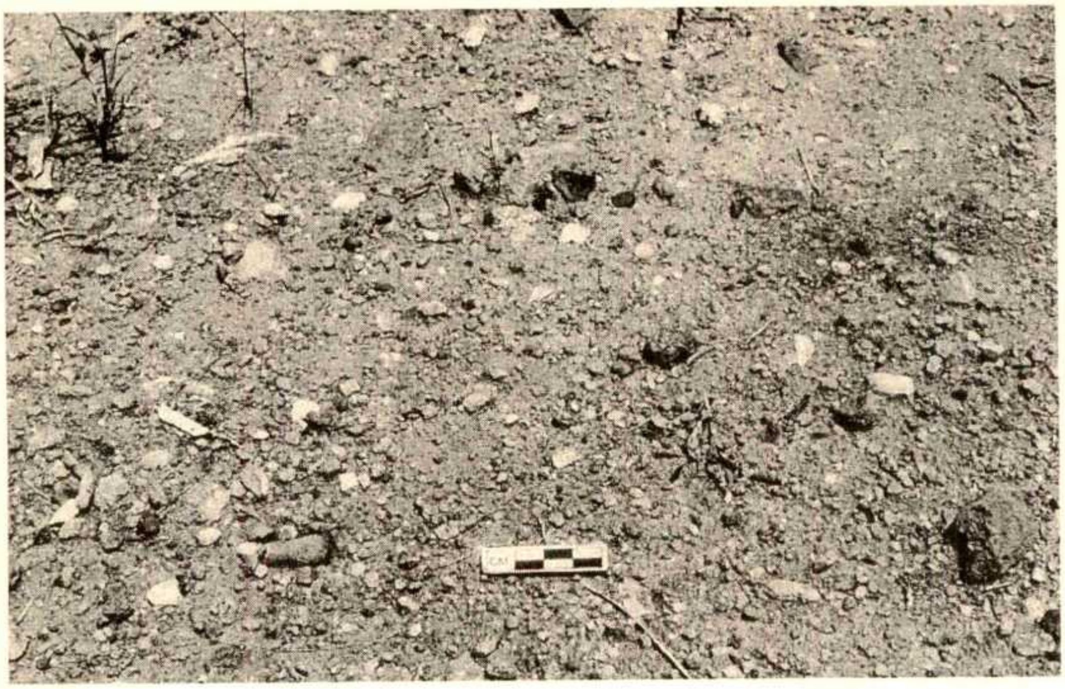

**Fig. 2**: Workshop area at Mahurjhari

**Table 1**: Bead manufacturing processes and raw material (from locality V, area 15 x 15 m).

| | Carnelian | Agate | Onyx | Quartz | Amethyst | Chalcedony | Jasper | Garnet |
|---|---|---|---|---|---|---|---|---|
| Raw material | 0 | 4 | 0 | 5 | 0 | 7 | 5 | 2 |
| Dressed cores | 10 | 0 | 0 | 4 | 0 | 3 | 0 | 0 |
| Bead rough outs | 6 | 0 | 0 | 1 | 0 | 1 | 1 | 0 |
| Micro chipped | 16 | 0 | 0 | 5 | 0 | 1 | 3 | 0 |
| Pecked | 16 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| Ground and not drilled | 16 | 15 | 0 | 3 | 0 | 4 | 1 | 2 |
| Ground and drilled | 58 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Broken while drilling | 8 | 1 | 0 | 3 | 0 | 1 | 0 | 1 |
| Drilled and polished | 8 | 2 | 0 | 4 | 0 | 0 | 0 | 7 |
| Polished and not drilled | 3 | 0 | 2 | 3 | 0 | 0 | 0 | 1 |
| Total | 141 | 23 | 2 | 29 | 1 | 17 | 10 | 13 |

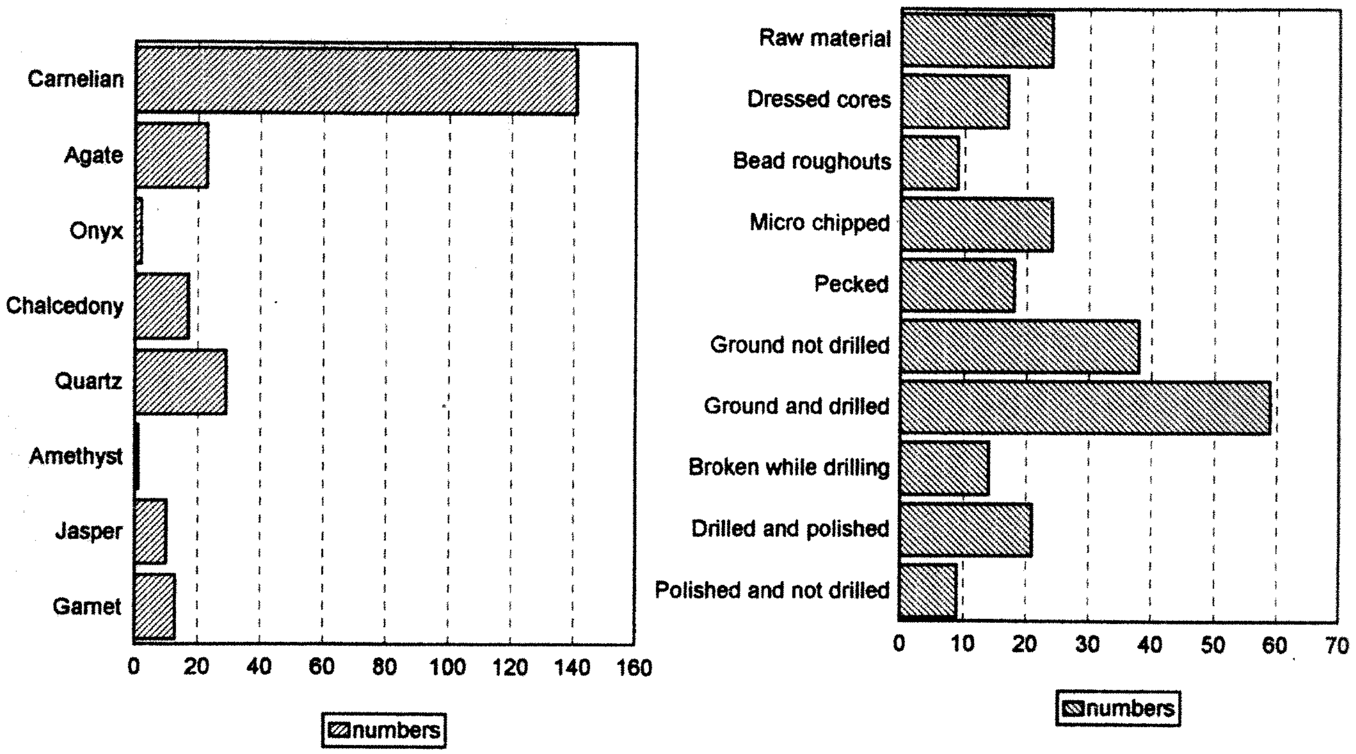

**Fig. 3**: Raw material used in bead manufacture

stones or in necklaces" (Deo 1973: 32). Besides, three hoards of beads and cabochons were recovered from the historical mound by a local farmer which he gladly handed over to the author. The assemblage comprised small oblate garnet beads (256), lozenge-form carnelian beads (189) and cabochons of carnelian (114), quartz (32) and agate (8).

Cabochons are hemispherical gem stones whose base is flat and unperforated. They are generally meant to be mounted into a metal bezel, either on a ring or clamped to a piece of jewellery.

*Raw material*

Agate, carnelian and chalcedony dominate the raw materials in the assemblage with onyx, red jasper, green jasper, varieties of quartz (milky quartz, quartz crystal, amethyst) and garnet (almandine) present in smaller quantities. The maximum size of the unused and partially worked nodules ranges between 7 to 10 cm. The garnet pieces are of 0.5 to 1 cm in size. Most of these raw materials are available within a radius of thirty kilometres. Chert and jasper are commonly found in the inter-trappean beds present in the area. Chalcedony, agate, quartz and other siliceous minerals also occur in the form of veins and nodules as secondary minerals in the Deccan Trap. Garnet is found as pebbles derived from Precambrian rocks exposed in eastern Vidarbha in the districts of Nagpur, Bhandara, Chandrapur and Gadchiroli (S.N. Rajaguru: personal communication). Garnet seems to have been procured from some riverine source as some of the beads are in the from of water-worn pebbles. They are irregular in shape and directly perforated. Inspite of the local availability of some of the raw materials, the quality and the scale of the bead manufacture demands organized procurement from a large catchment.

The Deccan Trap served as source of economic minerals and was probably exploited for various purposes from the time of the Indus Valley Civilization till the Early Historic period (Marshall 1931: 2: 680-681; 1951: 2: 731). Talking about the provenance of amethyst and quartz, Marshall tells us that "There is little doubt that the Mohenjo-daro material was derived from Deccan Trap" (Marshall 1931: 2: 680) and "The beds of the Kistna, Godavari and Bhima rivers have been specially noticed in this connection" (Marshall 1931: 2: 681). While analysing the beads from Mohenjo-daro, Marshall also suggested that carnelian, agates and onyx most likely came from the Deccan and Western India (Marshall 1931: 2: 681). From his Taxila collection he observed that "... carnelians and agates are more likely to have been cut and polished in the bazaars of Vidisa, Ujjayini, Brigukaccha (Barygaza) or Nasika, where the industry in these stones would naturally centre, ..." (Marshall 1951: 2: 731). Probably these gem stones were exported to Sindh from the Deccan and Western India from an early period (Niharika 1993: 41). At this juncture the bead manufacturing centre at Mahurjhari is significant as the craftsmen in a subsequent period might have moved to the source of raw material in central India around the beginning of the Iron Age in Vidarbha. The site is strategically located among the other Iron Age sites in this region and it might have been one of the centres which supported the supply of beads to the trading centres in western India as well as to the markets in southern India. On the basis of bead typology and material found at the Buddhist sites in Central Asia, Hunter (1933) suggested Mahurjhari "… was probably one of the many bead factories of Central India doing trade with countries as remote as Khotan and Rome…" during the Early Historic period.

*Shapes*

The shapes of the beads as indicated by the finished and unfinished beads found at different stages of manufacture were barrel, square barrel, truncated barrel, square bicone, truncated bicone, oblate, spherical or globular, tabular, discs, long cylindrical, annular, lozenge-form, lenticular, hexagonal and hexagonal truncated. There are a variety of etched beads and pendants on agate and carnelian.

## Stages of Manufacturing

The assemblages contain a large amount of raw materials in the form of nodules, blocks, fragmented pieces and naturally formed shapes especially in quartz crystals and garnet pieces (Fig. 4). Sometimes these were directly converted to beads after polishing the uneven surfaces and perforating them.

1. *Heating*

Initially the nodule or the stone is heated to remove the moisture for easy flaking. This is an age old practice which still continues to be used as shown by studies of the contemporary bead manufacturing centre at Khambhat. Evidence for this activity at Mahurjhari comes from the primary flakes removed from the core where the cortex of the flake often has the signature (colour change in case of carnelian and agate) of pre-heating. However, evidence of heating places could not be located on the surface.

2. *Primary chipping or dressing cores*

This stage is represented by a large number of dressed cores where the cortex has been removed to form workable bead blanks, with some initial formation of the shapes the beads might be going to take. Flaws/faults in the formation in the rock, cracks developed due to excessive exposure to heat, uncontrolled strokes which spoiled the probable

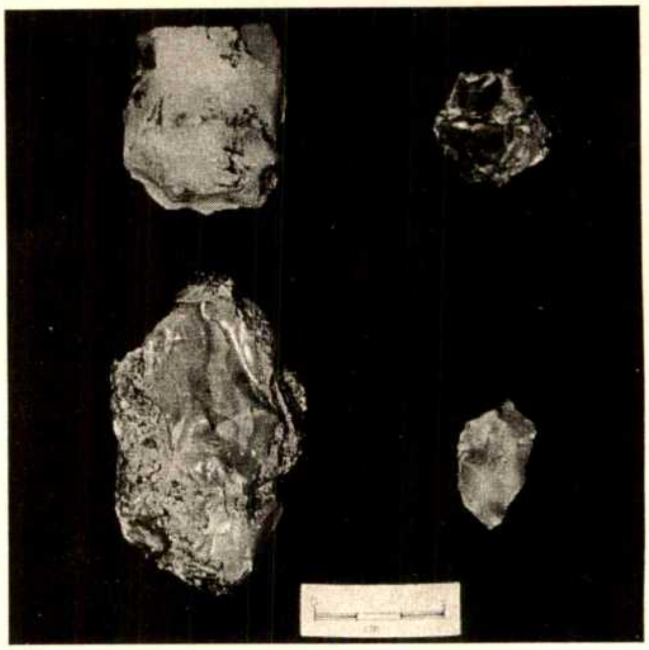

**Fig. 4**: Discarded raw material

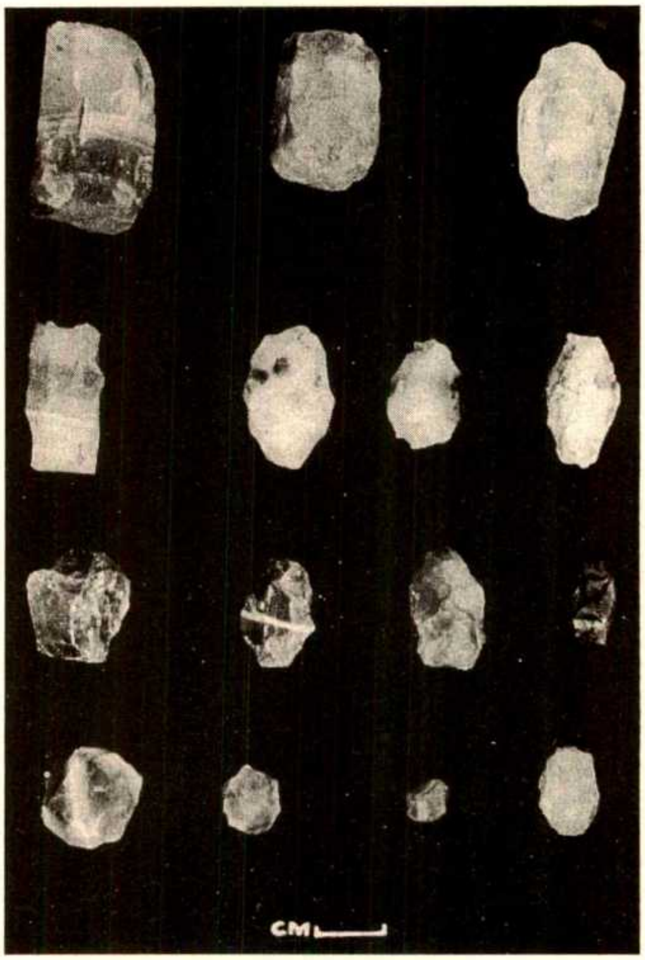

**Fig. 5**: Dressed cores

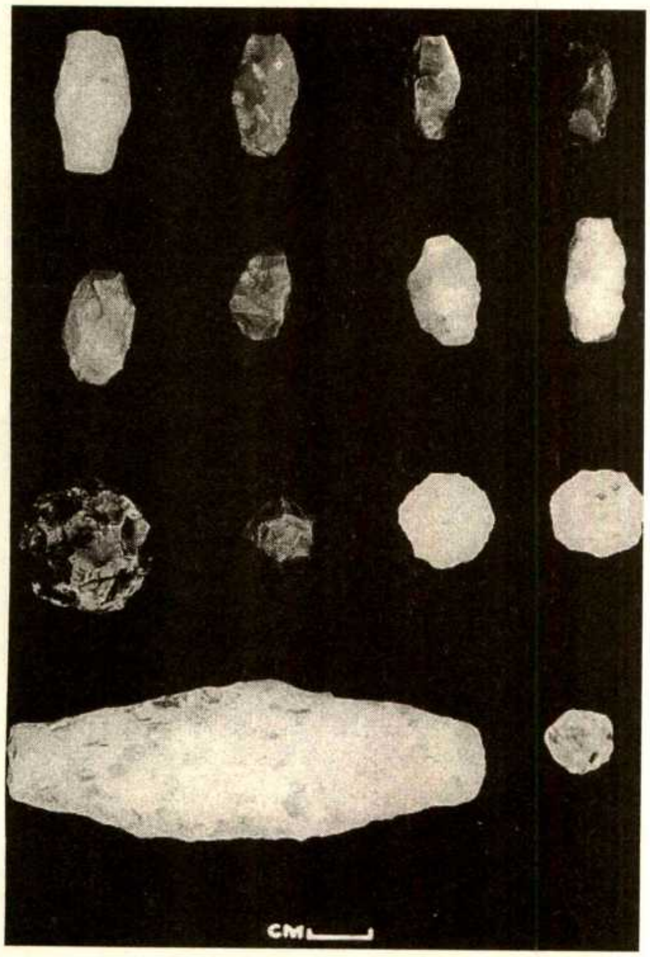

**Fig. 6**: Bead roughouts

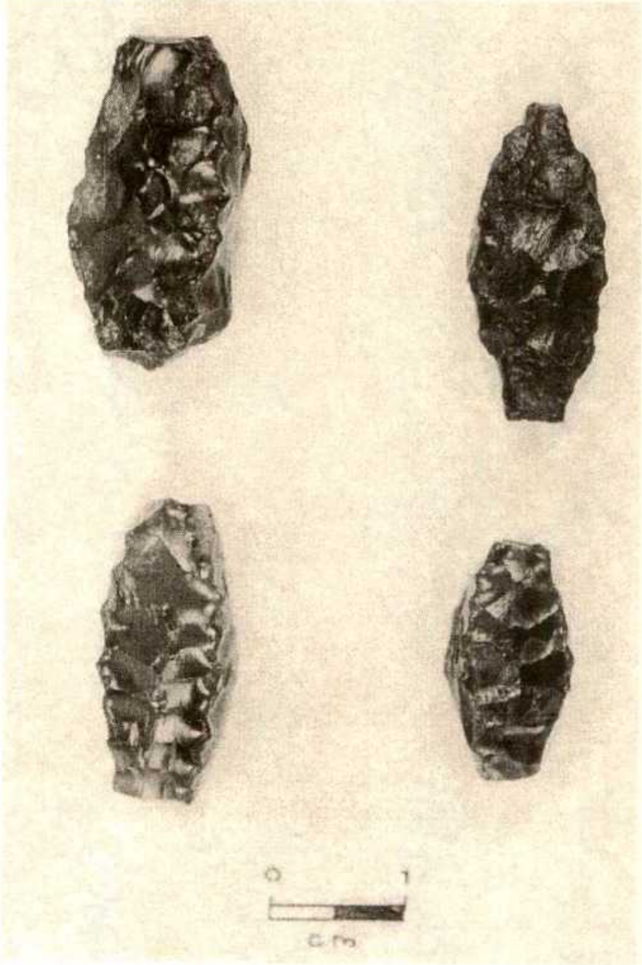

**Fig. 7**: Micro chipped beadblanks

intended shape resulted in a large number of partially worked nodules being discarded (Fig. 5). Some workable material might have escaped while sorting or storing for the next stage of processing. The debitage, especially big flakes produced out of this process is enormous in relation to the bead blanks found.

### 3. *Bead roughouts*

At this stage of the manufacturing process, worked nodules are reduced to bead roughouts by further chipping (Fig. 6). While doing so, some of the roughouts were selected for some types and sizes of beads which were probably not those intended initially. This selection seems to have taken place looking at the internal structure, especially in the case of banded agate where the banding was arranged to make a pattern.

### 4. *Micro Chipping*

In the subsequent stage beads are given a definite pre-intended shape by trimming the edges and surface with more controlled micro flaking (Fig. 7). Sometimes, where the rough edges of the shapes appear deep flake-scars are removed by careful trimming to refine the shape and the features of the faceted beads become clearer, well demarcated and prominent. In some cases these deep flake scars are visible even after the beads have undergone the final process of polishing.

### 5. *Pecking*

This method is not commonly seen at other bead manufacturing centres. It was adopted to smooth the surface. The bead went through a process of pecking or battering which removed the micro-flake scars and chipping marks turning the bead surface smooth (Fig. 8). It was probably intended to reduce the time and labour required for grinding.

### 6. *Grinding*

The initial grinding by abrasion was done to highlight and smooth the edges before the final grinding in the case of faceted beads. This also removed extra uneven marks

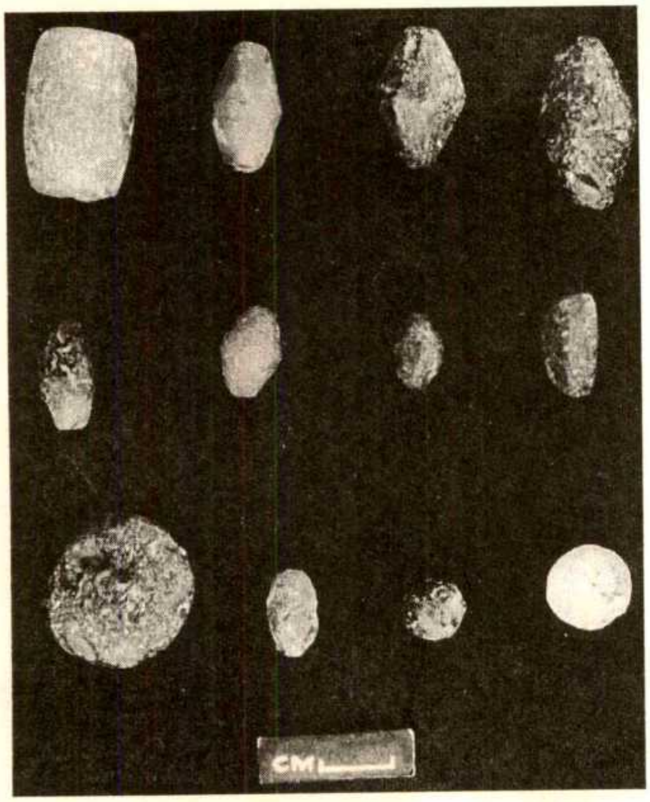

**Fig. 8**: Beads with pecking marks

which could not be erased during pecking while shaping globular, disc and cylindrical beads (Fig. 9). During the final grinding virtually all the flake scars and pecking marks disappeared, giving the bead a mat or greasy finish (Fig. 10). Most of the beads were found to have been drilled after this stage.

### 7. *Dimpling*

Before drilling, on both sides of the blank a mark was made to assist the drill. This process is known as dimpling. It is clearly visible in an oblate carnelian bead which after dimpling was polished without being drilled. It seems dimpling was done by pecking or drilling with a large diamond tip.

### 8. *Drilling*

The drilling was usually done from both sides. However, the drilling length from both the sides was usually not equal in most of the cases. For smaller beads, where the perforation required is less than 0.5 cm drilling was usually done only from one side. Sometimes when drilling from one side, chips were removed on the side opposite the drill due to the force of the drill when it pierces the bead. The perforations vary in diameter from 0.75 to 2.75 mm

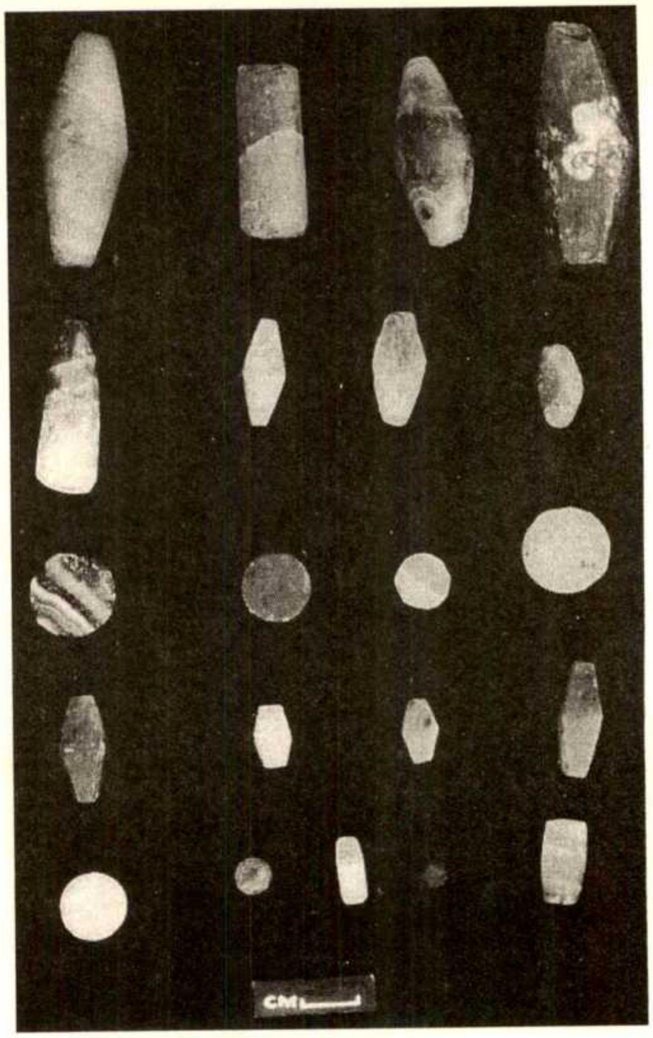

**Fig. 9**: Beads after initial grinding

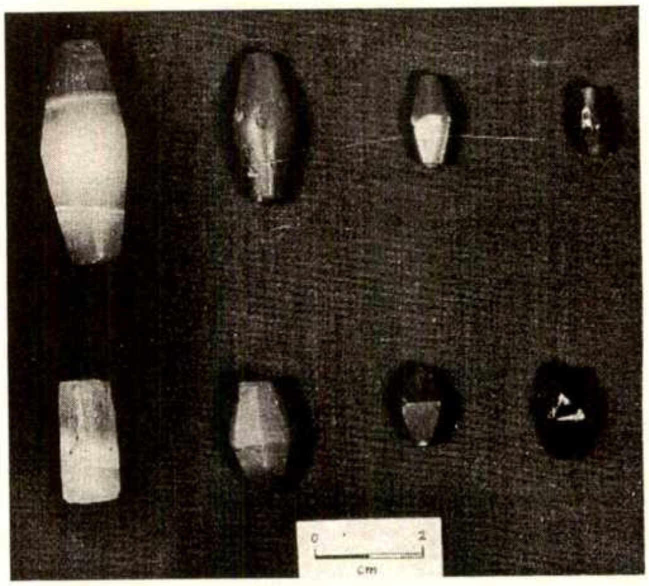

**Fig. 10**: Unperforated beads after final grinding

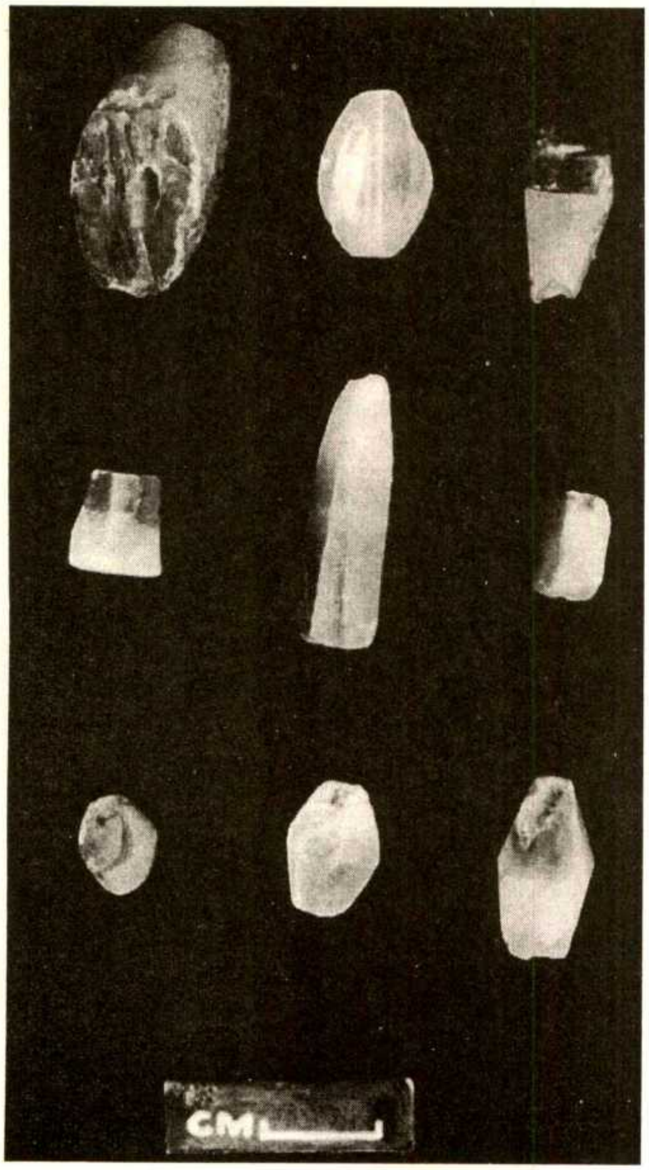

**Fig. 11**: Beads broken or abandoned during drilling

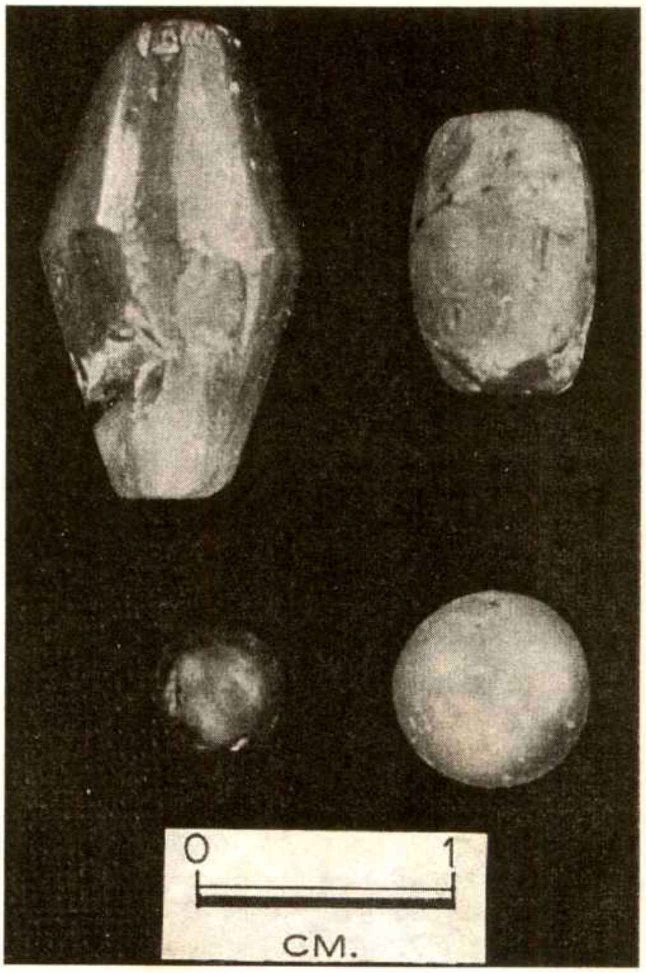

**Fig. 12**: Beads after the tumbling process

depending upon the shape and size of the bead. Though, this cannot be said for certain, it seems likely that the beads were drilled with single or with a double tipped diamond bit and with a bow drill (Peter Francis: personal communication). A large number of beads were found where the perforation was partially carried out and abandoned because of vertical splitting of the bead, chipping at one end and in some cases the line of perforations moving out of the centre (Fig. 11).

9. *Polishing*

This is the final step in bead making. After drilling, the bead was polished by abrasion against a bead polisher having a hard surface (probably a wood or bamboo plank plated with fine emery mixed with lac), especially in the case of most of the faceted beads. However, most of the rounded beads and some of the other types seem to have been bag polished by a tumbling process. In this method, any deep scars remaining on them are also polished to some extent though they do not have the kind of shine/radiance seen in the beads polished by a bead polisher (Fig. 12).

Polishing and drilling were labour consuming processes. Of these polishing appears to have been more crucial than drilling as most of the beads were polished after the drilling, so that breaking at the drilling stage was more tolerated rather than after polishing. A few beads with the final polish but without perforation were found in the assemblages.

## Discussion

Observation of the bead manufacturing debitage from Mahurjhari allows us to reconstruct the stages in bead production. These stages compare well with those documented at the present day bead manufacturing centre at Khambhat in Gujarat (Trivedi 1964; Possehl 1981; Kenoyer *et al.* 1991). The process of bead making can be broken down into three stages each with its different requirements of technical skill and labour. Differing availability of technical skill and labour might have resulted in the localization of the different stages. The initial stage is to procure the raw material. Here neither large amounts of labour, nor technical skill is required, but the raw material must be available from a natural source or obtainable from a trade network. Sites like Bagasra (Ajithprasad *et al.* 1998) and Atranjikhera (Gaur 1983) are probably raw material procurement sites as large amounts of unprocessed raw material was found here. The manufacturing of the beads involves the four major stages of shaping (knapping, chipping) pecking/grinding, drilling, and polishing. These four stages might have been carried out by different speacialized groups which might occasionally be at different localities. The beads might therefore have moved among these different groups either within the same site or between different sites. Both knapping and drilling are highly skilled tasks. On the other hand polishing is a labour intensive but relatively unskilled task. The process of drilling poses the risk of breaking the bead, while polishing poses no such risk. Therefore the ancient workers were reluctant to risk drilling a polished bead and consequently undrilled polished beads are rare. Their occurance, in view of the above mentioned risk, might show the unavailability of drilling specialists. Some sites where evidence for all the manufacturing stages are present are Mohenjo-daro, Chanhu-daro, Lothal, Arikamedu, Ujjain, Kodumal and Mahurjhari. Nevasa, Rajghat and Tilaura-kot show evidence for polishing and drilling but not for the shaping and procurement stages, so they should not be termed bead manufacturing sites, but rather bead processing sites. The final polishing stage is the most labour intensive, but does not require the highly skilled labour input of the earlier stages.

The identification of Mahurjhari as an Iron Age bead manufacturing centre has many implications. It is probably the earliest known Iron Age site in India which has given such evidence. It further emphasizes that besides specializing in iron technology, the megalithic people were also proficient in lapidary work. Probably, the local manufacture of beads is one of the factors explaining why grave goods at Mahurjhari were comparatively richer than those at neighbouring sites.

During the Megalithic period there are only four habitation sites known from Vidarbha, whereas, 89 burial sites have been recorded from this region. The absence of the former has made scholars think that in most of the cases the megalithic people led a nomadic or semi-sedentary way of life. However, the evidence of a lapidary centre at Mahurjhari, which required a major organized effort indirectly suggests a sedentary life during the Megalithic period at Mahurjhari.

It is possible that Mahurjhari probably has an Iron Age habitation mound which has not been located as yet. The reasons for such an assumption besides the presence of a bead manufacturing centre are:

a. It has a large number of megalithic burials like other habitation-cum-burial sites of this region.

b. Most of the skeletal remains from Mahurjhari suggest that they were in fresh burials, i.e. soon after death occured (Mohanty and Walimbe 1993). This suggests that the place of demise and the place of burial were not far from each other.

c. Mahurjhari like Bhagimohari and Khairwada began during the Megalithic period and continued till the Early Historic period. i.e. about 2nd/3rd century A.D.

## Conclusion

The Iron Age and Early Historic site of Mahurjhari in Vidarbha has revealed an extensive primary bead manufacturing centre. It has provided evidence of various stages of manufacturing processes along with enormous quantities of debitage. The new information that has come to light about bead making during the megalithic period is that after the initial processing and chipping, the roughouts are pecked into blanks. Subsequently, these blanks are ground by abrasion and then drilled. Besides, iron technology, the people of Mahurjhari were proficient in lapidary work, a craft specialization which was not common among the early megalithic builders and continued till early historic period. The wealth accrued out of the activity is reflected in their socio-economic behaviour.

## Acknowledgements

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# Archaeology for Children: A Note on the Sharma Children's Museum

Shanti Pappu, K.V Raman and N.C. Ghosh

Trustees, Sharma Centre for Heritage Education
Children's Garden School
11/12 Dr. Radhakrishna Salai
Mylapore, Chennai 600 004

The growth of archaeology in India depends to a large extent on generating popular interest in the discipline and in making it relevant to modern society. In this process of popularising Indian archaeology, children have been largely ignored. Knowledge of India's cultural heritage is principally confined to text books, occasional visits to museums and, in recent years TV programmes and multimedia products. The largely chronological and static approach adopted in text books, the absence of sustained interaction between teachers and professional archaeologists, lack of funds, the rigid examination oriented syllabus, and relative scarcity of popular literature on archaeology all serve as deterrents, and the child's sense of wonder about our past is often lost forever.

The Sharma Children's Museum (inaugurated on the 19th of February, 1999) is a venture of the Sharma Centre for Heritage Information, a registered non-profit public educational body aiming at the promotion of Indian Heritage among young people and at conducting independent research. At present the museum is housed at the Ellen Sharma Memorial Matriculation School (a sister venture of the Children's Garden School, Chennai). The museum is named in honour of the noted educationists Dr. V.N. Sharma and Mrs. Ellen Sharma who established the Children's Garden School in 1937. Inspired by their work at the Odenwald Schüle (École d'Humanité) in Switzerland, they aimed at uniting Western and Eastern ideas on education into a unique system that would enable children to develop their innate talents and to enjoy the experience of learning. The school has grown from a small group of seven children, to more than 3,000 children coming from varied socio-economic and religious backgrounds; including orphans, handicapped children and Tibetan refugees. The Ellen Sharma Memorial Matriculation School, is a rural institute situated at Sholinganallore, 30 km outside Chennai, and provides free and subsidised education to children from the neighbouring industrial areas and villages; and also caters to children from Chennai and other cities in India and abroad (Souvenir, Children's Garden School 1997).

The museum was planned by the first author, as an experiment in school education; a small step to overcome some of the deficiencies noted above in the teaching of our past. It aims at creating an innovative and informative museum environment where: (a) children can develop an awareness of Indian heritage; (b) a spirit of enquiry, wonder and imagination is stimulated and sustained; (c) archaeology is used as a tool to exercise skills in making judgements and critiques; (d) the past can be related to issues in daily life; (e) archaeological objects are used to teach principles of other social and physical sciences; (f) children are made aware of people (both belonging to past and present cultures) having different ways of life and belief systems; (g) local heritage issues are stressed; and (h) objects in the museum are used as a resource base for teachers for all disciplines taught in the school syllabus. We believe that in addition to gaining a better perspective of the past, issues in archaeology will sensitize children to modern problems such as degrading environments and changing value systems. The displays were designed in consultation with school teachers keeping in mind the school syllabus, the general developmental stages of children of different age groups and their varied social and economic backgrounds. The language of communication is both Tamil and English.

At present, the museum covers nine main themes (each comprising a diorama, a project/activity/game, and/or an interactive model), designed to encompass the scope of Indian archaeology ranging from the nature of the subject, its aims and methodology, associated sciences including Ethnoarchaeology, the story of human evolution, cultural phases ranging from the Palaeolithic to the Iron Age and a special focus on Tamil Nadu. The main dioramas are designed for children ranging in age from 10 to 16 years with supplementary displays for younger children. Dioramas (some designed to simulate a Mesolithic rock shelter or a Neolithic hut) have text, pictures, models and original artefacts, which convey information in a simple manner, address the basic questions of Where? When? Who? How? and Why? and aim at stimulating the imagination and further inquiry. Dioramas are supplemented by models, one of which depicts an archaeological excavation of a multicultural site, with reproductions of layers, figures of archaeologists and labourers, artefacts, antiquities, pottery, structures, equipment used, etc. This serves to explain basic concepts in archaeology and to satisfy the child's desire to know how sites and artefacts are discovered.

Concepts in archaeology are explained using a range of educational aids. These include a poetry book on fossils illustrated by the children and to be read aloud, interactive card games used for story-telling, creating short plays, games, and quiz competitions; and picture creation games. A carefully structured approach has been designed wherein each class is guided through the museum, with every visit focusing on a particular theme. The emphasis is not only on observation but includes discussions and questions and workshops on art and handicrafts or story-building, essays and quiz competitions where children are encouraged to freely express their feelings on what they have observed. A major focus in the museum is on the actual handling of artefacts by children. Children handle stone tools, describe them in terms of their physical properties, learn how they can be used and attempt to haft them with material provided. While this is not possible in the case of other antiquities, it has proved to be immensely popular and has encouraged them to treat finds with care.

We have adopted a multidisciplinary approach where archaeological objects and concepts are related to other social and physical sciences taught in the school curriculum. For example, the diorama on the Neolithic is associated with experiments on planting seedlings and other topics in environmental science; that on ethnoarchaeology encourages sensitivity in dealing with others from different backgrounds, castes, tribes or religions and so forth. With increasing feedback from teachers and students, each diorama is being modified to correct errors arising from differences in our preconceived assumptions and what the children find to be understandable and entertaining. The museum is bringing out a newsletter '*The Young Explorer*', and also organizes field trips to neighbouring archaeological sites and plans to hold lectures by eminent scholars. Since its inception, we have received a positive response from children and teachers. Teachers regularly use the museum to supplement text-book information, and numerous theme-based programmes involving more than 300 children have already been initiated. We have also observed that such museums located outside urban areas can indirectly play an important role in adult education. The museum attracted the attention of parents, carpenters and artisans among others. Artefacts on display caught their attention, in particular, when introduced to tool functions and their relation to present day professions-carpentry, metal work and farming; they could obviously relate to the early pioneers of human progress.

Further information on the museum activities can be obtained from the address given above or an email to spappu@vsnl.com. The museum is open only on prior intimation to the school authorities, in order to be able to design a structured tour based on the audience requirements. We would greatly appreciate any aid in the form of advise and suggestions for future development, as well as any artefacts, posters/pictures, photographs and books.

It is up to archaeologists to share some of our delight in the subject with Indian children and to ensure that *"The days when 'museum education' meant parties of schoolchildren being dragged round the display cases are long gone..."* (Eilean Hooper Greenhill 1994: 252).

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Dr. M. Sargurumoorthy and his colleagues at the Tamil Nadu Science and Technology Centre advised us on lighting, audio-visual and electronic aids.

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# Book Review

Jonathan Mark Kenoyer 1998. *Ancient Cities of the Indus Valley Civilization.* Karachi: American Institute of Pakistan Studies, Oxford University Press. pp. 280, Price Rs. 695.

The Western world and specifically the American public, though well informed about the ancient urban civilizations of Mesopotamia, Egypt, China, etc. should thank Professor J.M. Kenoyer for introducing them to another of the ancient world's highly developed urban civilizations, that of the Indus Valley through his well arranged travelling exhibition. This exhibition was organized through the Asia Society, New York and the Department of Archaeology and Museums, Government of Pakistan. This exhibition was also supported by the live demonstration of traditional techniques of pottery and beadmaking by master craftsmen from Pakistan. This exhibition: *The Ancient World of Indus Valley: Great Cities and Small Treasures* displayed for the first time in the United States of America a unique and important collection of artefacts from South Asia's first urban civilization. The present book: *Ancient Cities of the Indus. Valley Civilization* that accompanies the exhibition serves as an introductory text to make the public better informed and more appreciative of South Asia's importance as the birthplace of a unique and highly developed urban culture of the ancient world.

The most impressive and important aspect of this exhibition for me was to be able to see for the first time many original Indus Valley exhibits. A small colouring booklet: *Sarang and Jeevi: A Boy from Harappa and a Girl from Mohenjo-daro* with a story by Kenoyer was also released for the exhibition. This booklet utilizes current archaeological research and observations of traditional life in the cities and villages of modern Pakistan and India to provide an entertaining colouring story book which teaches children about the ancient ways of life of the Indus valley people. At the Elvehjem Museum of Art, University of Wisconsin where this exhibition was on display I watched many batches of children using this book which appears to have been very popular with them. This is a very interesting way to make children appreciate other cultures. I think Indian museum curators should take a clue from this booklet to make the 'boring' archaeological exhibits more entertaining and educational for the young museum visitors.

Most of the data presented in this book derives from the recent excavations and work at Harappa by Kenoyer and his colleagues under the Harappa Archaeological Research Project. Using the most recent data and contextual archaeological analyses of the material, Kenoyer has tried to present a balanced perspective of the Indus Valley Civilization. This book is written keeping the general public in mind. Archaeological jargon is avoided making it not only readable for the general public but also a useful source of information for students of South Asian archaeology. Professor Richard Meadow has rightly pointed out in his preface to this book that the "most skeptical professionals can profitably mine the text for new data and new interpretations on the Indus Valley Civilizations, especially the catalogue of objects given at the end of this book".

Chapter 1 of this book is an introduction. It begins with the history of the discovery and the background to the Indus Valley Civilization followed by a discussion on the terminology and the theoretical framework.

One of the controversial issues in the Indus Civilization is the terminology used between 5000 to 1300 B.C. In the past a variety of terms have been used liberally and now scholars have started recognizing the limitations of such terms. While specifically referring to the process of cultural development in South Asia, Kenoyer uses a complex framework in which three major cultural traditions have been identified. Each tradition is divided into temporal eras of which there are four distinct ones in the Indus Tradition: Early Food Producing Era; Regionalization Era; Integration Era; Localization Era. This reflects a comprehensive theoretical and chronological framework and is an effective framework to fit the massive and ever-changing archaeological database. He however, uses the general term Indus Valley Civilization to refer to the period of urban expansion and cultural integration that corresponds to the Integration Era. Finally, a brief but useful discussion of the environment and climate is also presented in this chapter.

Chapter 2, Origin of Urban Societies, begins with a summary on stone — using hominids, and moves through the Middle to Upper Paleolithic hunter-gatherers up to the development of the early food production stage. This is followed by a discussion of the regional cultures that provided the foundation for the emergence of later urban centres and the Indus culture. Kenoyer proposes four preconditions, which were necessary for the development of cities and state-level societies. These preconditions are closely interrelated and together provided the foundation for the development of urbanism and the the state-level society of the Indus Tradition.

The first precondition is diversification of the subsistence base and resources resulting in the potential for the production of surplus. The second major precondition for the rise of cities is the development of social and economic interaction networks between major ecosystems and resource areas. New technologies that developed in conjunction with trade began to fulfill the third major precondition for the rise of urbanism, which is the presence of appropriate technologies to build and maintain cities. The final precondition is the differentiation in status based on access to essential resources and the ability to control distribution. Kenoyer argues that all these preconditions were fulfilled in slightly different ways and in different combinations in each culture or phase of the Regionalizaton Era.

The character and organization of Indus cities, towns and villages are dealt with in Chapter 3. Based on size, physical structures and centrality, Kenoyer identifies four levels of settlements. In the first level are the largest settlements of Mohenjo-daro (+200 ha.), Harappa (+150 ha.), Ganweriwala and Rakhigahri (+80 ha) and Dholavira (100 ha). Recent research has indicated that the cities were not created in a short time by visionary rulers or architects, but rather grew out of villages that had existed in the same locality for hundreds of years. Beginning with relatively small populations, they grew in size and density to become larger settlements. The second level of settlements are a few towns and small cities (10 to 50 ha.) such as Judeirjo-daro and Kalibangan. The third level of settlements comprises small villages or hamlets (less than 1 and up to 10 hectares) such as Amri, Lothal, Chanhu-daro, etc. Each settlement contributed to the support and maintenance of the larger urban centres. Based on recent research Kenoyer also discusses the city planing and the architecture of Dholavira, Harappa and Mohenjo-daro.

Based on new discoveries at Harappa and other sites, in Chapter 4, the enigmatic Indus script is presented along with a new perspective on the context in which this writing was used. According to Kenoyer, the Indus script represented a shared set of symbols and beliefs that was spread out over an extremely large geographical area. These shared beliefs must have played an important role in the integration of the urban and rural populations and would have been reinforced by the exotic ritual items obtained through trade or created by new technologies.

One of the important discoveries in recent years made by the excavation team at Harappa is the evidence for an Early Indus script in the form of multiple abstract symbols that were inscribed on pottery prior to or after firing. Some of the symbols are identical to the characters used in the later Indus script and even occur in the same sequence. Kenoyer is of the opinion that they represent the same sounds or meanings. The Early Indus script was probably distinct from the more widespread use of potters' marks, because such marks continued to be used even after the invention of the script. This pattern of use suggests that their function was different and, to some extent, independent of writing itself.

Chapter 5 is devoted to examining the nature of the ruling elite and traders using as evidence the archaeological remains left by these communities. A new analysis of specific artefacts which are interpreted in relation to factors of socio-economic control and integration.

Since the discovery of the Indus Civilization archaeologists have tried to locate artefacts that could be used to identify the rulers and political leaders. However, the results have been contrary to their expectations. Kenoyer believes that it is because the Indus Valley Civilization does not follow the general pattern found in other early urban societies. Given the historical pattern of ancient India the images of rulers or coins with the images of rulers appear for a brief period during Kushan Period. But these imperial visages disappear immediately after the foreign rule with the rise of the indigenous Gupta rulers. It is therefore not surprising that we do not have images of rulers building temples or conquering human enemies like the other contemporary early urban societies of Mesopotamia and Egypt. Instead, the Indus rulers appear to have governed their cities through the control of trade and religion rather than military might. Rulers carried striking carved seals with animal symbols and writing, and wore ornaments made with secret technologies and rare raw materials. These symbols of wealth and power were what set the rulers apart from the ordinary people and they also reflect the many different social and economic levels that were controlled by the rulers.

Kenoyer uses a similar approach in Chapter 6 for understanding religious art and the symbols that represent the ideology of the Indus culture and reinforce the structure of Harappan society. Many objects and symbols have been seen as representing Harappan religious practices, and such beliefs were important in the legitimization of both socio-economic and political power. Kenoyer's contextual study of ritual objects and symbols shows a vertical hierarchy of identical symbols using different qualities of raw material.

For example, beads of certain designs were made in painted terracotta, painted steatite, bleached carnelian and naturally patterned stone. There are also differences in distribution: seals were common over large areas, while terracotta figurines were confined to a smaller area around Harappa and are uncommon in Gujarat and the upper Ganga-Yamuna region. This may reflect the relative importance of the beliefs that served to maintain the social and ritual hierarchy within the settlement and among the different regions.

Discussion on the many different social classes and ethnic communities that made the Indus cities are presented in Chapter 7 using as a principal source studies of the many diverse types of artefacts found in Indus cities. Specific sets of artefacts are used to characterize the nature of the daily life of men and women living in the Indus region, beginning with childbirth and concluding with death and burials.

Chapter 8 focuses on the craft and technologies that were developed in the Indus cities, with special emphasis on crafts that were used to create symbols of wealth and power. Kenoyer distinguishes four categories of crafts at Indus Valley sites: 1) those processing local materials using simple technologies — woodworking, terracotta production, house building, etc.; 2) those processing non-local raw materials using simple technologies — chipped, ground and pecked stone; 3) those processing local material using complex technologies — stone bangle manufacture, elaborate and specialized ceramics, inlaid woodwork, etc.; 4) those processing non-local materials using complex technologies — agate bead manufacture, seal production, copper/bronze metal working, precious metal working, shell working, faience working, etc. Kenoyer argues that categories depending upon complex technologies (categories 3 and 4) would involve standardization, while the other categories would be expected to show a high degree of regional variation. Political control of craft production could assume the form of control of technological knowledge, of labour, of access to the raw material, and of distribution. Kenoyer thinks some crafts were apparently structured on the basis of kin networks and were decentralized as to state control. Others may have involved long distance kin networks and alliances that could be decentralized in terms of central control but required some centralized support to maintain long distance trade relations. Crafts that were difficult to control directly were less important for the state economy, while easily controlled crafts could have been important for the state economy.

The concluding chapter deals with the many factors leading to the decline of the Indus cities and the localization of socio-economic interaction networks. This is followed by a discussion of the legacy of the Indus civilization and its contribution to the later cultures of the Subcontinent. Prior to very recent studies, most scholars thought the introduction of new pottery styles, plants and animals represent the intrusion of new people. This along with the discovery of unburied skeletons among the latest levels of Mohenjo-daro combined with inaccurate reading of the Vedic texts led to the claim that the decline of the Indus civilization was the result of the "invasion" or "migration" of Indo-Aryan Vedic communities.

New research shows that contary to the earlier theories the final phase of the Harappan phenomenon saw a process of de-urbanization and localization rather than extinction. The localization era is a period after the integration of the Indus Tradition and before the early urban states beginning around 700 to 600 B.C. Although the Localization Era covers the decline of Indus cities, it is also a time of regional development leading up to the rise of new cities in the larger geographical area encompassed by the Indo-Gangetic Tradition. In each major region of the Indus Valley, small city states or chiefdoms began to reorganize society and consolidate regional power. These regional powers destroyed the integration achieved by the Harappan phase cities and established new peripheral polities in Afghanistan and Central Asia and to the east in the Ganga-Yamuna Doab. In both regions the rise of new polities is clearly seen as an indigenous process and not the result of outside invasion.

Additional details about the Indus Valley Civilization are presented in the form of a catalogue of important objects. These include artefacts obtained from the major excavations at Mohenjo-daro, Harappa and Chanhu-daro during the ninteen twenties and thirties. Other objects in this section have been excavated in the last three decades at the sites of Harappa, Mehrgarh, Nausharo, Allahdino and Miri Qalat. The catalogue has 205 black and white photographs along with a short description of the object, its dimensions, material, museum catalogue number and reference to the publication.

Bibliographic references are cited for the text as endnotes to each chapter and for the catalogue as a bibliography. A comprehensive bibliography of all references cited in the text and catalogue are also provided in the book. A comprehensive index of important topics, names and places mentioned are provided at the end of the book.

Kenoyer's long experience of living and working in India and Pakistan along with his detailed ethnoarchaeological and experimental studies on traditional crafts have provided him with a unique insight into the culture of the Subcontinent. This is further enhanced by his ability to speak many languages of the Subcontinent. His experience of living in two diverse cultures has helped him as an anthropologist to provide flesh and blood to the skeleton of archaeological data. The picture he paints about the ancient way of life with a broad brush still remains impressionistic as also pointed out by Richard Meadow. Kenoyer concludes his foreword on an optimistic note when he writes that "further excavations and research and eventually the decipherment of the Indus script will change many of the interpretations presented in this book". In due course the ongoing research programme at Harappa and other Indus Valley settlements will eventually help to modify and supplement the interpretations presented in this book, possibly even by the author himself.

The book is profusely illustrated with excellent maps and illustrations along with high quality black and white, and colour photographs. The publishers, Oxford University Press deserve our warm congratulations for the excellent quality of the printing. The price has been deliberately kept very low so that individual scholars and students of India and Pakistan can easily afford it. This book will be a welcome addition to any university or even school library.

Kuldeep K. Bhan
Department of Archaeology,
M.S. University of Baroda,
Vadodara

# Book Review

*Beginnings of Urbanization in Early Historic India.*
1998. Satyendra Kumar Jha. Patna: Novelty and Co.
Pages 325, Price Rs. 550/-.

Every student of Indian history and archaeology is familiar with the idea of urbanization occurring in two phases, the first in the valley of the Indus and its tributaries, and the second in the vast flood plain of the Ganga. We are told that several cities emerged in the fertile alluvium of the Ganga valley during the mid-first millennium B.C. Several large urban centres such as Vaishali, Kaushambi, Rajagriha, Pataliputra, Shravasti and Ahichchhatra flourished between c. 600 B.C. and 100 B.C.-100 A.D. To trace the origin, development and the decline of these urban centres from the historical and archaeological angles forms the subject matter of Dr. Satyendra Kumar Jha's book. Dr. Jha being an officer of the State Directorate of Archaeology, Bihar is directly involved in the recovery and management of archeological data in Bihar. Beginning with his doctoral dissertation in 1989, the present book is part of his ongoing research on urbanization in the Ganga valley.

The problem of the origin and the decline of large cities in Early Historic India is not a straightforward one for a variety of reasons. Cities like Varanasi, Hastinapur and Rajagriha have been amply referred to in the literature of the period between 600 B.C. and 500 A.D. However, relating these textual references to the archaeological record of this period has proved to be rather problematic. Jha has critically evaluated both the sources of the texts and the archaeological record relating to the second urbanization. Jha mentions the need to integrate both the data obtained from ancient texts as well from archaeological excavations and explorations. It is important to note that he is aware of the need to follow entirely different inference procedures while handling literary and archaeological sources.

Socio-cultural changes around half a millennium before the Christian Era are important to understand the origins of the urban phase in the Ganga valley. Historians designate the century around 600 B.C. as the period of social and economic transformation. To archaeologists this period is that of the Northern Black Polished (NBP) pottery. However, the amount of archaeological evidence of this crucial period in Indian history is inadequate. Jha clearly mentions that although several early historic sites have been excavated "... there has been very little horizontal excavation". Obviously this puts serious limitations on the inferences regarding town planning and settlement hierarchy. A further limitation mentioned by Jha is the long delay in publication of excavation reports.

Jha's introductory chapter provides a critical summary of previous contributions. If one wishes to understand the problem of urbanization in early historic India, reference to two studies is indispensable: fieldwork based settlement archaeological investigations by Makkhan Lal (1984) and George Erdosy (1988). Jha has extensively used their conclusions and has pointed out differences in their methods as well.

Jha has divided his subject matter into five chapters: introduction; technological base of urbanization; settlement pattern and demographic features; physical construct and town planning; and chronology and diffusion. These chapters contain a discussion of the various points and the conclusions drawn by the author. However, a separate synthesis by the author based on his conclusions would have added to its value.

Jha has chosen a style of using footnotes and end notes, and has discussed analytical and survey methods briefly. For example, he mentions the nearest-neighbour analysis done on the data of Allahabad District (p. 141). He gives the formulae used by George Erdosy as well as Makkhan Lal. However, more discussion on such methods. particularly regarding their utility, assumptions and limitations is necessary considering the diverse academic background of prospective readers. Jha has used a graphical form to represent his results; this is rare in books on historical discussions.

Anyone dealing with the study of early historic societies faces the hard task of negotiating obstacles in the chronological interpretation of ancient works such as the Mahabharata and Arthashastra, as well as the works of grammarians like Panini and Patanjali. Jha finds that many texts are of limited value for understanding settlement hierarchy, demographic features and technological advances in early historic India. It is noteworthy that the author discusses all the constraints put on his data *before* he attempts to use various archaeological and textual data sources. He does not bank on them as an escape route while interpreting the archaeological record in the light of historical-religious texts.

By and large, a common feature of historical narratives is that the factual content gets buried under piles of opinions and hypotheses about historical processes as often authors tend to use decorative and flowery language. However, Jha's language is simple and effective. He has demonstrated the complexities of methodological and theoretical issues involved in dealing with the origins and evolution of the early historic urban centres in the Ganga valley. One of the strong points of this book is the unfolding in clear terms of the finer dimensions of the problem to readers.

Pramod Joglekar
Deccan College
Pune 411 006

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# Obituary

**Shankar Annaji Sali**
(1927-1999)

Dr. S.A. Sali was born on 5th May 1927 at Sangamner, District Ahmednagar and died on 30th January 1999. Dr. Sali's entry into Archaeology occurred under very unique circumstances. In 1950 he was a young clerk working in the Bank of Agriculture, Sangamner, when a new kind of pottery was noticed by him at the village of Jorwe, near Sangamner. Sali was so impressed with this pottery that he brought it to the notice of both Dr. Sankalia at Deccan College and Shri M.N. Deshpande of the Archaeological Survey of India. This was the first discovery of a Chalcolithic Culture in Maharashtra, and this phase was labelled Jorwe after the site of its first discovery. Dr. Sali, at that time a matriculate, was encouraged by both Dr. Sankalia and Shri M.N. Deshpande and turned to Archaeology as a career, joining the ASI. From that beginning in 1950, he not only acquired all the further academic qualifications upto a Ph.D., but in the 35 years until his retirement in 1985 contributed to all the phases of Prehistory.

Most of us probably do not realise that the first identification of every phase in Maharashtra's Prehistory was made by Dr. Sali. He discovered the first evidence for Acheulian when he found a handaxe near Sangamner which was referred to by Sankalia in his book "The Godavari Palaeolithic Industry". Sali identified a number of Middle Palaeolithic sites in the Dhule district. However these discoveries are overshadowed by his contribution to the Chalcolithic and Upper Palaeolithic in Maharashtra. During the period 1956-1976, he was posted at Dhule, and assigned the task of a village to village survey which resulted in his discovering a large number of sites. He identified the Savalada and Late Harappan cultures in the Tapi valley. In 1972-1973 Sali excavated the Upper Palaeolithic and Mesolithic site of Patne. His long held view that "microliths" belonged to the Pleistocene period was vindicated. A number of phases of Upper Palaeolithic were identified. Ostrich eggshells were associated with the Upper Palaeolithic and dated to 25,000 years B.P. The ostrich eggshell bead from Patne remains the earliest dated art in India.

Dr. Sali's excavation at Daimabad between 1976-1979 was meticulously carried out. He was successful in publishing his excavations so ensuring a permanent contribution to Chalcolithic studies. The site of Daimabad has the largest number of phases of the Chalcolithic and a new Chalcolithic culture labelled "Daimabad culture" was identified by Sali from these excavations.

In addition to these major contributions — exploration of Dhule District, excavation of Daimabad and Patne, Sali made very important contributions to the study of the Quaternary and to the Lower and Middle Palaeolithic. Along with the late Dr. R.V. Joshi, he excavated the Lower Palaeolithic site of Gangapur, near Nasik and the site of Nandur Madhemeshwar. He also excavated the Lower Palaeolithic site of Yesar/Badne near Sakri. Dr. Sali was one of the first to realize the complexity of the Quaternary record. The widespread presence of fissured clays in the earlier Quaternary, the numerous episodes of filling and cutting and the importance of palaeosols were recognized by him much earlier than by others. He believed that there was evidence for Quaternary tectonics in the Tapi valley and while this was never accepted by most archaeologists, recent geologically oriented studies agree with his findings.

My own interaction with Dr. Sali was confined to a few field trips and meetings when he visited Deccan College. My appreciation of him is therefore not on the basis of a personal interaction but on the basis of his academic contributions. I admire the fact that he saw that his two major excavations at Patne and Daimabad were published. Although, I am sure he could have written more, nevertheless he published 40 research articles. Although he retired as a Superintending Archaeologist from the ASI, much of his work was carried out as a simple excavation assistant. He used whatever opportunities came his way to pursue with sincerity, and hard work, his interest in Archaeology.

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Sheila Mishra
Department of Archaeology
Deccan College
Pune 411 006

# Obituary

**Professor Shankar Tewari**
(1928-1988)

It is with deep sorrow that I am writing about the sad and untimely demise of Professor Shankar Tewari, formerly Professor of Geography in Hamidia College, Bhopal who passed away on 11th April, 1998 after a brief illness. Prof. Tewari was also well-known as an archaeologist, an antiquarian, an explorer and a photographer of high calibre.

Professor Tewari was born on 18th July 1928 in Mungeli village, Bilaspur District, M.P. His father, the late Pandit Ram Gopal Tewari, was a freedom fighter and later became an MLA and Chief Secretary of the Central Provinces. After his initial education at the Government High School, Bilaspur he graduated from Morris College, Nagpur where he studied geography and specialised in geomorphology. Professor Tewari developed an interest in varied fields of research which involved a lot of exploration and field work, hiking and making collections. Being a dynamic person he was not content with just classroom teaching and a routine 10 am to 4 pm job. As a lecturer at Robertson College, Jabalpur, his teaching methodology had varied facets which included on the spot visits to various areas of interest, much discussion both on a one to one basis as well as with groups, rather along the lines of Shantiniketan. As a student he was an active member of various literary societies and took a keen interest in extra-curricular activities. He was a man with a multifaceted personality and it is difficult to do justice to him as a student, teacher, researcher and human being in this brief obituary.

One of the earlier discoveries of Professor Tewari was in 1952, when he found the subterranean Kutumsar cave, situated about 30 km away from Bastar and 200 m below the surface of the earth thus rivalling even the Carlsbad cave of the United States. Being an excellent photographer himself, he ventured to take photographs of this underground cave, perhaps for the first time in our country. These photographs adorned the walls of his living room in Bhopal. Some of these photographs have been published in prestigious journals like the *National Geographic* and the *Illustrated Weekly of India*. Inside the Kutumsar cave he discovered, for the first time, some new varieties of fish and a species of cricket, the latter was named *Keimpiola shankarii* in his honour. Some unique varieties of pearls were also discovered by him in the cave which, so far, were known only from the USA, France and Russia.

Professor Tewari was a great teacher of geography and particularly of his favourite subject geomorphology, and he liked to take students to remote areas, sometimes in mountainous terrain to make his point. He was one of the first to consider the relevance of weathering on the rock shelters and consider them from a geographical perspective.

Amongst Professor Tewari's many discoveries of rock shelters are the ones at Jaora, Bhopal, Dharampuri, Ganesh Ghati, Firangi, Imeliya and Imlana in M.P. In addition, Professor Tewari discovered a Chalcolithic site at Pipaliya Lorka on the bank of Kaliasot in Bhopal District. Jhalka Kheda, Ninnour, Nandaur and Nandur are some of the sites that were discovered by him belonging to the Historical period in Raisen District. Many of these sites have been excavated and it is suggested that the inhabitants of these sites were responsible for making the paintings on the nearby rock shelters during the Historical period. Inspite of the fact that Prof. Tewari was not associated with a research organisation or with the Central or State Archaeological Survey it goes to his credit that he was instrumental in getting the State Archaeological Survey to excavate some these sites.

Professor Tewari had a rich collection of coins, particularly punch-marked coins datable to the 3rd century B.C. as well as some modern ones from more than a hundred countries. He was an avid stamp collector and his collection comprised stamps from various countries, of important personalities and events, and also of wildlife in which he had a very deep interest. He had thousands of slides of archaeological and geological interest and his other passions included gardening and the rearing of pets. It is worth mentioning that during one of his surveys Professor Tewari was attacked by a bear in the forests around Obaidullagunj but his presence of mind, sharp reflexes and determination forced the bear to run away.

In a brief but eventful stint as the Director of Tourism in Madhya Pradesh in 1971, Professor. Tewari was responsible for finalising the first tourist map of the State and made even the unknown and little known monuments and tourist places popular by setting up Tourism Development Boards.

As a man Professor Tewari, though short tempered at times, was kind hearted and generous, helpful in the right spirit even if somewhat outspoken. He had no double standards and was forthright. If he knew he was wrong he had the greatness to admit it and he would not hesitate to apologise whenever he felt that he had hurt the sentiments of others, irrespective of who the person in question may have been. Non-materialistic by nature, keen to do something worthwhile for the subjects of his interest, Prof. Tewari was a friend, philosopher and guide to his students and other scholars who approached him for advice and guidance. Compassionate, selfless and utterly dedicated, he was rather a misfit in these days of greed, non-truths and selfishness that plague even some of the finest educational institutions. However, none of it deterred him from his principles which he cherished till the last.

I was fortunate to have earned his faith and affection and he would share with me knowledge of all his precious collections and researches. He attended my excavation camps in the Narmada Valley twice and gave valuable suggestions regarding the geomorphological behaviour and history of the river and its tributaries.

In Prof. Tewari's death the world of scholars and teachers has lost a pillar who will continue to stand out for ages. He travelled widely to almost every nook and corner of the country in order to fulfill his interests as he was essentially a 'field man' rather than a ' table scholar'. He wrote several articles and widely popularised subjects of his interest. Such a man will always be missed by friends, scholars and students alike.

G.L. Badam
Deccan College
Pune 411006

# Indian Society for Prehistoric and Quaternary Studies

c/o, Department of Archaeology, Deccan college, Pune 411 006

## Report of the General Secretary for 1998-99

The functioning of the Society during the year under report has been quite satisfactory, both academically and financially. The regular activities of the Society were carried out successfully. The financial position is reasonably sound because of the interest accruing on the fixed deposits and annual grants from the Archaeological Survey of India for publication of the Journal and from the Indian Council of Historical Research for publication of the Journal as well as for organizing the Annual Conference. We are grateful to these organizations for their financial support. An audited statement of the accounts of the Society for the year 1998-99 will appear in the December issue of the Journal.

### Man and Environment

This is the tenth year of biannual publication of the Journal. The journal has maintained its standard and continues to attract a wide range of articles contributed by scholars from within and outside the country, with a steadily increasing circulation.

We sincerely thank and acknowledge the efforts of Mr. Sujit Patwardhan and his staff at Mudra Press for their excellent cooperation in the production of the Journal.

### Annual Conference

The 26th Annual Conference of the Society was held under the auspices of the Department of Ancient History,Culture and Archaeology, University of Allahabad, from 14 to 16 November 1998, in conjunction with the annual conferences of the Indian Archaeological Society and the Indian History and Culture Society.

The following members participated in the conference:

R.C. Agrawal, P. Ajithprasad, G.L.Badam, Bhamini Mahida, D.K. Bhattacharya, R.S.Bisht, Subrata Chakrabarti, P. Binodini Devi, K.N. Dikshit, Kiran Dimri, S.P. Gupta, Bulbul Hingalajia, Juvena Jalal, J.P. Joshi, P.S. Joshi, R. Korisettar, K. Krishnan, Ravindra Kumar, P.K. Rao, B.B. Lal, Makkhan Lal, Abhijit Majumdar, Varsha Makwane, V.D. Misra, V.N. Misra, R.K. Mohanty, Malti Nagar, A.K. Narain, Amarendra Nath, Jeetendra Nath, J.N. Pal, J.N. Pandey, P.V. Pathak, Sadasiba Pradhan, Col. A.K. Prasad, B. David Raju, V. Ramabrahmam, Vijay Sathe, V. Selvakumar, Kajal Shah, M.L. Sharma, T.C. Sharma, Y.D. Sharma, A. Singh, B.P. Singh, V.H. Sonawane, K. Srinivasulu, A. Sundara, Rakesh Tewari, P.K. Thomas, Alok Tripathi, D.N. Tripathi, Vibha Tripathi, R.K. Varma, T.P. Verma.

The conference was inaugurated by the Education Minister of Uttar Pradesh, Mr. Gaur on the morning of 14th November. Prof. V.D. Misra presided over the function. Dr. J.N. Pal and Dr. J.N. Pandey welcomed the delegates.

After the inaugural function Prof. D.N. Tripathi, President of ISPQS presented his Address, followed by those of the Presidents of the IAS and IHCS.

The academic sessions of the conference began from the afternoon of the 14th and continued on the 15th and 16th November.

The following papers were presented at the Conference:

Ravi Korisettar — Quaternary Studies in the Malaprabha Valley

Subrata Chakrabarti — The Stone Age Prehistory in Birbum

T.P. Verma — Some Recently Discovered Prehistoric Sites in Eastern U.P. and Bihar

J.N. Pandey — The Microlithic Industries of the Vindhyan Plateau and the Gangetic Plains: their Antiquity and Possible Economic Implications

G.L. Badam, V.D. Mishra, J.N. Pandey and J.N. Pal — Further Research on the Palaeontology of Son Valley

A.K. Singh and Anil Kumar — The Evidence of Horse in the Indian Peninsula (Pre to Early Historic Period)

Vijay Sathe — Analysis of Enamel Ultrastructure in Archaeology

K. Krishnan and R.A.E. Coningham — Petrographic Analysis of Rouletted Ware and Associated Ceramics of the Early Historic Period

D.K. Bhattacharya — The Problem of Interpretation in Indian Archaeology

P. Ajithprasad, V.H. Sonawane, K.K. Bhan, S. Pratapchandaran and Abhijit Majumdar — Excavations at Bagasra — 1997-98

R.C. Agrawal — Excavations at Kara Tepe, Usbekistan

Abhijit Majumdar — Early Harappan Settlements in North Gujarat

Kiran Dimri — Post-Urban Harappan Settlements in Central Saurashtra

V.N. Misra, V.S. Shinde, R.K. Mohanty, Lalit Pandey and Jeevan Kharakwal — Further Excavations at Balathal, Dist. Udaipur, Rajasthan (1997-98)

R.K. Mohanty — Chalcolithic Pit-dwellers of Central Narmada Valley

P.V. Pathak — Ėkavrsa — The Sacred Bull: Royal Emblem on the Indus Seals and AV Hymns V.16 and VI.86

P.V. Pathak — On the Nature of the Indus Seals: Problems and Prospects

Bhamini Mahida — Teracotta Art of Bagasra

A.S. Sundara — Rock Engravings in the Sahyadri Ghat and Coastal Region

M.L. Sharma and Vighanesh Kumar — Ostrich (?) in Rock Art and Archaeology in North-East Rajasthan

A.K. Prasad — Recent Discoveries of Rock Paintings, Palaeolithic Industries and other Artefacts in Nawadah, Jamui, Gridih and the Kodarma District of Bihar

M.L. Sharma and Vighnesh Kumar — Newly Discovered Rock Art Site in Marwar Region

V. Selvakumar — Iron Age-Early Historic Cultures of the Gundar Basin, Tamil Nadu

P.S. Joshi — The Megalithic Culture of India: The Second Turning Point

S.K.Bhatt — Proto-Numismatic Tradition in India

Surgyani, M.L. Sharma & Chhaju Ram — Fifty Years of Archaeology in Rajasthan

### Professor H.D. Sankalia Memorial Lecture

The Professor H.D. Sankalia Memorial Lecture was delivered on 14 November by Mr. J.P. Joshi, former Director General of the Archaeological Survey of India, on *Harappan Civilization as seen at the Close of the 20th Century* during the Society's conference at Allahabad. The Lecture will be published in a later issue of the Journal.

### Professor H.D. Sankalia Young Archaeologist Award

No paper was submitted for the award.

### Dr. Malti Nagar Ethnoarchaeology Award

There was no contestant for this award. According to the guidelines of the Award, a paper on Ethnoarchaeology read in the conference could be judged by the members on its merit and, if found worthy the author could be given the Award. The paper entitled " A Study of the Megalithic Culture found among the Maramus of Manipur", presented by Dr. P. Binodini Devi during the conference was highly praised. The members present during the session recommended her for the Award. She is the recipient of the first Dr. Malti Nagar Ethnoarchaeology Award and the Award was presented by Dr. Malti Nagar herself.

At the concluding session of the conference held on the evening of 16th November, warm thanks were given to Prof. V.D. Misra, the Conference Organizer and Dr. J.N. Pal and Dr. J.N. Pandey, Local Secretaries, for the excellent arrangements for the conference and the warm hospitality extended to the delegates.

### Life Members

The following 20 scholars joined the family of Life Members of the Society during 1997-98.

1. Ms. Megha A. Chandvankar, 2. Mr. D. B. Chitale, 3. Ms. S.B. Darsana, 4. Ms. Ambika Dhaka, 5. Prof Sumit Guha, 6. Ms. Neha Gupta, 7. Ms. Juvena Jalal, 8. Mr. Manoj Kumar Singh, 9. Mr. Binaya Kumar Khilar, 10. Mr. Manoj Kumar, 11. Mr. Sanjay Kumar, 12. Ms. Varsha Makwana, 13. Dr. Richard H. Meadow, 14. Ms. Ajita K. Patel, 15. Mr. Arakhita Pradhan, 16. Ms. Dishaa Rao, 17. Ms. Menaka Rodriguez, 18. Dr. A.K. Singhvi, 19. Mr. M.C. Srivastava, 20. Mr. M.P.Tiwari.

The total number of Life Members now stands at 378.

### Meetings of the Executive Committee

A meeting of the Executive Committee was held at 1.00 p.m on 15th April 1998 in the Society's office in the Department of Archaeology, Deccan College, Pune.

The following members were present:

1. Prof. V.N. Misra, 2. Dr. P.K. Thomas, 3. Dr. Statira Wadia, 4. Dr. R.K. Mohanty, 5. Dr. P.P. Joglekar, 6. Dr. Sheila Mishra, 7. Dr. P.P. Dandwate.

In the absence of the Chairman, Prof. A. Sundara and the Vice-Chairman, Prof. V.D. Misra, Prof. V.N. Misra, General Secretary, presided over the meeting. The following points, as per the agenda communicated earlier, were discussed and resolutions passed accordingly.

1. The Committee accepted the voluntary resignation of Dr. V.S. Shinde as Treasurer and appreciated his contribution to the Society.

2. The Committee unanimously agreed to appoint Dr. P.P. Dandwate as Treasurer of the Society in place of Dr. V.S. Shinde.
3. It was decided that the appointment of Dr. P.P. Dandwate should be ratified at the General Body Meeting.
4. Consideration of honorarium of the secretarial staff: The Committee felt that as the work load of the secretarial staff is increasing day by day, the honorarium paid to them should be suitably enhanced. It was decided that the honorarium should be enhanced to Rs. 1800/- and Rs. 900/- in place of Rs. 1000/- and Rs. 600/- respectively.
5. The Committee discussed that, a) the Society should have a permanent Income Tax Number. and b) to obtain Income Tax exemption it should be registered as a Charitable Organization.
6. The Committee resolved that the Society should apply for transfer of its registration from Ahemdabad to Pune. In case it is not feasible, the Society should apply for fresh registration to the Charity Commissioner, Pune. The meeting ended with a vote of thanks to the Chair.

**Meeting of the General Body of the Society**

The General Body meeting of the Society was held at the premises of the Department of Ancient History, Culture and Archaeology, University of Allahabad, at 5 p.m on 16th November, 1998.

The following members were present:

R.C. Agrawal, P. Ajithprasad, G.L. Badam, Bhamini Mahida, D.K. Bhattacharya, R.S. Bisht, Subrata Chakrabarti, P. Binodini Devi, K.N. Dikshit, Kiran Dimri, S.P. Gupta, Bulbul Hingalajia, Juvena Jalal, J.P. Joshi, P.S. Joshi, R. Korisettar, K. Krishnan, Ravindra Kumar, P.K. Rao, B.B. Lal, Makkhan Lal, Abhijit Majumdar, Varsha Makwane, V.D. Misra, V.N. Misra, R.K. Mohanty, Malti Nagar, A.K. Narain, Amarendra Nath, Jeetendra Nath, J.N. Pal, J.N. Pandey, P.V. Pathak, Sadasiba Pradhan, Col. A.K. Prasad, B. David Raju, V. Ramabrahmam, Vijay Sathe, V. Selvakumar, Kajal Shah, M.L. Sharma, T.C. Sharma, Y.D. Sharma, A. Singh, B.P. Singh, V.H. Sonawane, K. Srinivasulu, A. Sundara, Rakesh Tewari, P.K. Thomas, Alok Tripathi, D.N. Tripathi, Vibha Tripathi, R.K. Varma, T.P. Verma.

The meeting was presided over by Prof A. Sundara, Chairman of the Society.

The following business was transacted at the meeting.

The report of the activities of the Society for the year 1997-1998 was presented by Prof. V.N.Misra, General Secretary of the Society. It was unanimously approved by the members present.

The Annual Audited Statement of Accounts for the Year 1997-98 was placed before the General Body by the General Secretary and was unanimously approved by the members present.

The General Body of the Society accepted the resignation of Dr. V.S.Shinde as Treasurer of the Society and acknowledged his contribution to the Society.

**President of the Society for 1999**

Prof. V.N. Misra proposed the name of Mr. K.N. Dikshit as the President of the Society for the year 1998-99.The proposal was unanimously accepted by the members present.

**Professor H.D. Sankalia Memorial Lecturer**

Prof. V.N. Misra proposed the name of Dr. S.P. Gupta for Prof. H.D. Sankalia Memorial Lecturer for the year 1998-99. The proposal was unanimously accepted by the members present.

**Election to the Executive Committee**

As the term of the previous Executive Committee was coming to an end by 31st March 1999, the members present during the General Body Meeting elected the following Life Members of the Society to the Executive Committee for a term of three years i.e. 01.04.99 to 31.03.2002.

| | |
|---|---|
| Chairman | Prof. V.D.Misra |
| Vice Chairman | Dr. R.D. Chaudhury |
| General Secretary | Prof. V.N. Misra |
| Joint Secretary | Dr. P.K. Thomas |
| Asst. Secretary | Dr. R.K.Mohanty |
| Treasurer | Dr. P.P. Dandawate |

Executive Committee Members:

Dr. K. Krishnan
Dr. K.P. Rao
Dr. P.S. Joshi
Dr. Ravi Korisettar
Dr. B.L. Nagarch
Dr. P.V. Pathak
Dr. Vijay Sathe
Dr. Sheila Mishra
Dr. J.N. Pandey
Dr. Malti Nagar
Dr. Statira Wadia
Dr. P.P. Joglekar

The General Body appreciated and acknowledged the contribution of the outgoing Executive Committee Members.

The meeting ended with a vote of thanks to the Chair.

30.5.1999

(V.N. Misra)
General Secretary

## INDIAN SOCIETY FOR PREHISTORIC AND QUATERNARY STUDIES

c/o Department of Archaeology, Deccan College, Pune 411 006

### BALANCE SHEET AS ON 31st MARCH 1999

| **Funds and Liabilities** | **Rs.** | **Rs.** | **Properties** | **Rs.** | **Rs.** |
|---|---|---|---|---|---|
| Trust Funds or corpus Bal. as per prev. B/S | 558,543.40 | | Immovable Properties | | |
| Ajustment during the year | | | Bal. as per prev. B/S | 00.00 | |
| (Donations recd during the year) | 00.00 | 558,543.40 | Add: During the year | 00.00 | |
| | | | Less: Sold during the year | 00.00 | |
| Other Earmarked Funds— | 83,607.95 | | Less: Depreciation @ 5% | 00.00 | 00.00 |
| (Created under the provisions of the trust | | | | | |
| deed or scheme or out of the income) | | | Investments (As per Schedule II) | | 1,071,169.86 |
| Depreciation fund | 00.00 | | | | |
| Sinking fund | 00.00 | | Other Movable Properties (As per Schedule III) | | 110,951.39 |
| Reserve fund | 420,654.65 | 504,262.60 | | | |
| | | | Bal. as per prev. B/S. | | |
| Loans (Secured/Unsecured) | | | Add: During the year | 00.00 | |
| (As per schedule) | | | Less: Sold during the year | 00.00 | |
| For expenses | 245.72 | | Less: Depreciation @ 5% | 00.00 | |
| For Advance | 00.00 | 245.72 | Loans (Secured and Unsecured) | 00.00 | |
| | | | Loans Scholarships | 00.00 | |
| For rent and other deposits | 00.00 | | Other Loans | 00.00 | |
| Audit fee | 2,200.00 | | Cash & Bank balance | 00.00 | 00.00 |
| Provision for Contribution | 788.94 | 2,988.94 | | | |
| | | | Cash | 2,001.27 | |
| Income & Expenditure A/C. | | | Bank Balances | 106,595.72 | 108,596.99 |
| Bal. as per prev B/S | 00.00 | | | | |
| Less: Appropriation if any | 00.00 | | Income Outstanding | | |
| Add: Surplus per inc& Exp A/C | 224,677.58 | 224,677.58 | Rent, Interest, Other Income | 00.00 | |
| | | | Cash | 00.00 | |
| | | | Bank Balances (As per Schedule IV) | 00.00 | 00.00 |
| | | | Income & Expenditure A/c | | |
| | | | Bal. as per pre B/S | 00.00 | |
| | | | Add: Deficit for the year | 00.00 | 00.00 |
| Total Rs. | | 1,290,718.24 | Toral Rs. | | 1,290,718.24 |

As our report of even date

FOR A.S. CHANDVANKER & CO., CHARTERED ACCOUNTANTS

Date: 28.09.1999
Place: PUNE

A.S. CHANDVANKER

(V.N. Misra)
GENERAL SECRETARY

(P.K. Thomas)
JOINT SECRETARY

(P. Dandawate)
TREASURER

## INDIAN SOCIETY FOR PREHISTORIC AND QUATERNARY STUDIES,

c/o Department of Archaeology, Deccan College, Pune.

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDING 31ST MARCH 1999.

| Expenditure | Rs. | Rs. | Income | Rs. | Rs. |
|---|---|---|---|---|---|
| To Expenditure in respect of | | | By Rent* (Accrued/Realised) | | 00.00 |
| Properties | | | | | |
| Rent, Taxes, Cases | | | By interest* (accrued/Realised) | | |
| Repairs and Maintance | | | On Securities | 00.00 | |
| Salaries | | | On Deposits | 204,407.00 | |
| Depreciation (by way of prov. or adjustment) | | 23,362.84 | On Loan | 00.00 | |
| Other expenses | | | On Bank Account | 3,194.00 | 207,601.00 |
| To Establishment Expenses | | 45,402.33 | By Divident | 00.00 | |
| To Renumeration to Trustees | | | By Donation in cash or kind | 00.00 | |
| To Remuneration (in the case of Math) to the head of Math including his household expenditure | | | By Grants | 25,000.00 | 25,000.00 |
| | | | By Income from other sources in details as far | | |
| To legal fees | | | as possible | 00.00 | |
| To interest paid | | | —ICHR Grant RCD (conference) | 00.00 | |
| To Audit fees | | 2,000.00 | Life Membership fees | 38,470.00 | |
| To Contribution and Fees | | | M&E Volume sale | 44,163.00 | |
| To Amount written off | | | Sale of DHP | 900.00 | 83,533.00 |
| To miscellaneous Expenses | | 00.00 | | | |
| To Depreciation | | | By Transfer from Reserve | | |
| To Amount transferred to reserve or specific fund | | 20,691.25 | | | |
| To expenditure on object of the trust (as per schedule 'A') | | 00.00 | By Deficit carried over to B/S | | |
| To surplus carried over to B/S | | 224,677.58 | | | |
| Total Rs. | | 316,134.00 | Total Rs. | | 316,134.00 |

As our report of even date

FOR A.S. CHANDVANKER & CO., CHARTERED ACCOUNTANTS

Date: 28.09.1999
Place: PUNE

A.S. CHANDVANKER

(V.N. Misra)
GENERAL SECRETARY

(P.K. Thomas)
JOINT SECRETARY

(P. Dandawate)
TREASURER

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